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WORKSHOP PRACTICE

VOLUME VI

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PREFACE

THE working and surface treatment of sheet and plate metals plays a prominent part in some branches of engineering and in allied trades, such as the manufacture of domestic utensils and the like.

In Section XXIV a general outline of methods adopted in the working of sheet and plate metals is given. The treatment is confined mostly to principles rather than to giving detailed information concerning specialized work, such as the manipulation of duralumin and other aluminium alloys now so much employed for all-metal aircraft purposes. Of especial interest are those parts of the section dealing with the testing of materials, such as the Erichsen test, and the strains and stresses to which plate and sheet metals are subjected during their working. Jointing, brazing, soldering, annealing are all adequately dealt with.

Section XXV deals with zinc coating, galvanizing, sherardizing, annealing, lead coating, electro-plating, lacquering, cosletizing, and enamelling. The two sections thus form a concise and comprehensive work of reference for sheet and plate metal workers and others desiring to study the subject.

Dr. Merritt in his section on gear-cutting deals very completely with the subject, and after a general introduction, in which he tells of the origin, development, and principles of gearing, goes on to explain modern methods of gear cutting. The section is accompanied

by a particularly fine set of illustrations. Cutting, hardening, and gauging all receive attention.

The two concluding sections are newly contributed. They deal respectively with the work of the heavy plating shop and with the various methods and appliances by means of which materials and products are moved from place to place. Both sections are adequately illustrated and will amply repay careful study.

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SECTION XXIV

THE WORKING OF SHEET AND PLATE METALS

BY

E. ARTHUR ATKINS, M.I.MECH.E., M.I.W.E.,

AND

WILFRID A. ATKINS, M.INST.MET., M.INST.I.S.

SECTION XXIV

THE WORKING OF SHEET AND PLATE METALS

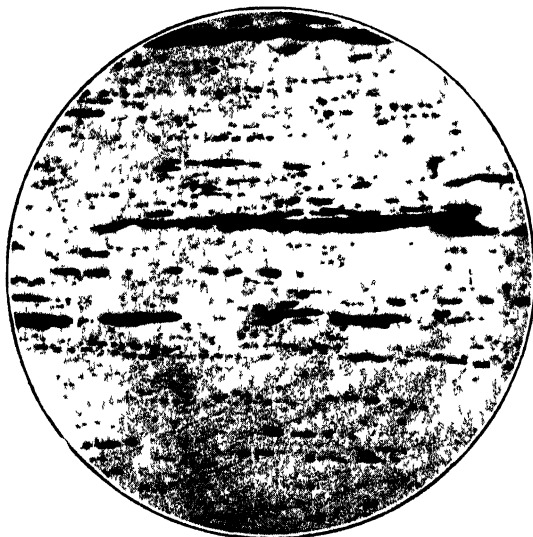
THE TESTING OF SHEET METAL

THE greater number of sheet-metal workers have no means of testing the metals they are required to work other than by the use of the ordinary tools of the workshop. For wiring, grooving, and other forms of joints, the sheet-metal worker soon gets into the knack of being able to test the quality of thin sheets by simple feel or bending at the corners. This sense of "feel," or workshop intuition, is one which in the best class of workman is very highly developed, and enables the operator to determine quickly whether or not a certain kind or quality of sheet is suitable for the purpose for which it is required. The expert workman who has to hollow, raise, spin, or stretch sheet metals instinctively knows when he has carried the sheet sufficiently far in the operation before it requires annealing.

The best test of material is, however, the actual working up of the metal into the particular shape required; but even this test, unfortunately, will not give the same result with two different workmen, as some operators acquire the habit of knowing just how to manipulate a metal (or "humour" it, as the old-time workman used to say), so as to obtain the best results from its working, which means that the sheet metal will be brought into its required shape with the least amount of work or punishment put upon it.

This kind of manipulation can only be brought about through the workman taking thought as to what is

happening to the metal whilst it is passing through the punishment of being hammered into shape or being otherwise treated. The inefficient workman can usually be detected as the one who hammers or knocks about the sheet metal in quite an unnecessary manner, and whose hammer or mallet blows are delivered without



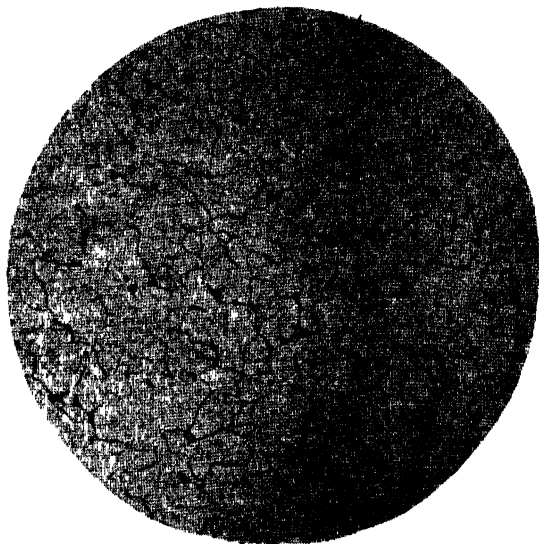
(Magnification 100 diameters)

FIG. 1. MICROSCOPIC STRUCTURE OF WROUGHT IRON

very much thought as to their consequences. The best operator of sheet metal is the one who can make the most out of material which is of the poorest quality.

Before the incoming of mild steel, the working of common wrought iron sheets was in itself quite an art, as the sheet-metal worker had to pay so much attention to wiring, grooving, knocking-up, hollowing, etc., if he wanted to avoid the cracking of the sheet in the direction of its fibres. Examination of the structure

of common wrought iron under the microscope readily explains why it is so easily fractured when a bend is made in the direction of its fibres, which is usually lengthways of the sheet. Fig. 1 shows a photomicrograph, to 100 diameters magnification, of a piece of highly-polished wrought iron; the so-called fibrous



(Magnification 100 diameters)

FIG. 2. MICROSCOPIC STRUCTURE OF MILD STEEL
(ANNEALED)

character of the material is due to nothing else but alternate layers or threads of slag and iron. In the photomicrograph the slag threads are shown in black. As these threads or laminations of slag are very brittle it can easily be understood when wrought iron sheet is of a very slaggy nature it will quickly break, the fracture following the direction of the slag fibres.

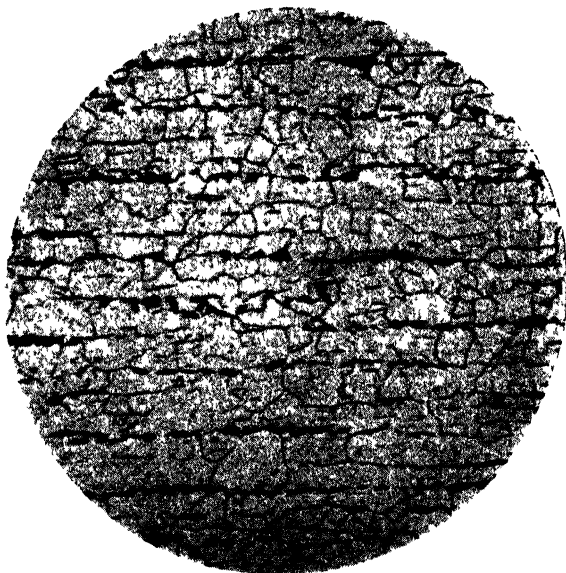
Well-made mild steel is of quite a different structure, as will be seen by the photomicrograph (Fig. 2).

The structure exhibited by this photomicrograph shows that the material is in the unrolled annealed state, and in this case the small black areas, instead of being composed of slaggy material, really represent the "steely" portion of the mild steel, for here it will not be out of place to mention that steel is not a perfectly homogeneous or uniform material, the purest mild steel being composed of grains of practically pure iron, together with small crystals or grains of steel, the steel in all cases having the same composition of 0.85 per cent carbon. Therefore (Fig. 2), while it represents a mild steel of 0.12 per cent carbon, in reality it is composed of practically pure grains (white) of iron, with small grains (black) of 0.85 per cent carbon steel. Seeing that the structure of the mild steel and wrought iron is so entirely different, it will readily be understood that the steel, having no slag threads or fibres, will stand up against bending when in the form of sheet much better than the common wrought iron.

A mild steel sheet, however, which has not been properly annealed after rolling may have its "steely" constituents in the form of threads or bands, as shown in the photomicrograph (Fig. 3). This photomicrograph is of a 0.13 per cent carbon steel sheet, and shows the structure of the material in its rolling or longitudinal direction, and if a sheet of this description were bent in such a manner that the bend lay along the direction of rolling it would inevitably fracture. However, if this type of rolled sheet were properly annealed, the bands would disappear and be replaced by small black areas as shown in Fig. 2, and in that case would be equally tough in both directions.

Where sheet metal has to be used for ordinary purposes, a simple test is to cut pieces about 3 in. wide both crossways and lengthways of the sheet, double these over and hammer close down with a mallet.

The quality of bend will indicate something of the suitability of the sheet for working-up purposes. If when it is hammered down close there is no sign of fracture at the outer skin of the metal at the bend, it is fairly certain that this quality of sheet will be good



(Magnification 100 diameters)

FIG. 3. MICROSCOPIC STRUCTURE OF MILD STEEL
(AS ROLLED)

enough for grooving and wiring. If in addition to hammering the sheet close up with a mallet it can be opened out straight again, this will be an indication of extra toughness and the suitability of the sheet for more severe work than is required for either wiring or grooving. This convenient method, however, of testing the quality of sheet metal can only be acquired after considerable practice.

Where sheets are required for stock purposes, the

above method of testing has the disadvantage that the material may have been bought and paid for long before it comes into use ; hence, it is always advisable, where large quantities of sheets are carried, that they should be ordered to a definite specification, and carefully tested to ensure they are up to the specification before being placed in stock.

Nowadays, most progressive firms have a well-organized routine metallurgical testing laboratory to check all incoming raw material used in their particular manufactures. This laboratory is usually well equipped with one or more good-quality tensile and compression testing machines, complete with autographic or extensometer instruments. These are used to measure very small increases in permanent deformation on samples of sheet, strip, etc., after subjection to stresses in tension. Other equipment comprises hardness testers, bend test machines, and microscopic apparatus, used for taking the photomicrographs illustrated in this book.

The usual tests carried out on deep-drawing material are: (1) Maximum or ultimate stress at which the sample breaks. (2) Yield point. (3) Elongation on 2 in. and 8 in. The figures for best results with iron and steel are M.S. = 18–20 tons per square inch; Y.P. = 12–14 tons per square inch; elongation on 2 in. = 50 per cent min., and on 8 in. = 25 per cent min.

With cold-rolled springy material another test has to be applied, called the “proof stress.” This is defined as the stress in tons per square inch which can be applied to a specimen without causing more than a certain predetermined amount of permanent elongation. This elongation is usually taken as 0.1 per cent, or 0.15 per cent of the gauge length chosen, and is measured by the extensometer.

As will be shown later on, the size of grain, quite apart from the hardness or softness of the sheet,

exercises a good deal of influence upon its working properties, and as the grain size of metal is considerably affected by both cold working and methods of heat treatment, it is exceedingly important that this should be taken into account where sheet metal for deep stamping purposes is required to be used.

ERICHSEN TESTING

In testing sheet metal physically, the simplest and most rapid means of determining the "draw" of a metal is perhaps that made in the Erichsen draw machine. This simple apparatus consists essentially of a block of cast iron in which is a lateral aperture, at each side of which is mounted a circular grip or die with a central opening. One die is fixed, the hole in which is visible in an inclined mirror attached to the above-mentioned block. The other die is mounted on a screwed sleeve which screws into a corresponding tapped opening in the side of the block opposite the fixed die. When this is screwed up to the fixed die the two dies meet exactly together.

Inside the screwed sleeve there is another screwed shaft with a protruding knob or tool at the end running on ball bearings, which is free to revolve independently of the shaft. The sleeve and the shaft are connected or disconnected at will by a simple clutch device, the whole assembly being bolted to a large diameter hand wheel with exterior spokes to enable a better leverage to be obtained. On the inside of the wheel is fixed a frictional metal collar marked off in millimetres and decimals thereof. When the clutch is withdrawn the collar rotates with the wheel and internal shaft and tool.

The test pieces are cut about 3 in. square, which allows them to be inserted into the lateral opening of

the block, which is, of course, bolted down to some rigid support. The two dies are screwed apart by the hand wheel sufficiently to allow the sheet to pass between them, after which the dies are turned until the sheet becomes gripped between them. The collar on the wheel is now moved round until the zero mark on it corresponds to a fixed scale bolted to the block, and which is marked off in millimetres, 5, 10, 15, etc. The outside sleeve is now secured from revolving by a small wing-nut at the side of the block, the clutch withdrawn, and the wheel caused to revolve. During this operation the tool forces itself into the sheet through the fixed die, and the increasing "dome," or "hump," is watched closely in the mirror. As soon as a crack appears on the dome, turning is stopped, and the depth of impression is read off on the scale and collar. Before commencing a test the thickness of sheet should be accurately measured by means of a micrometer, as the depth of impression increases with increase of thickness on identical material.

The moment of fracture can usually be felt by the wheel when a slight "give" occurs, but when testing spring hard material, or, indeed, sometimes with dead soft sheet, a distinct crack is heard. Light should be just visible through the crack when the specimen is taken out of the machine.

A sketch of a sample of 22 gauge brass, after being tested in the machine, is shown in Fig. 4; a sketch of a sample of 12 gauge aluminium is illustrated by Fig. 5; whilst Fig. 6 shows a piece of 20 gauge tinplate after being tested. In the above sketches the fracturing of the "dome," or "hump," will be seen as indicated in each case.

The depth of impression gives a fairly accurate estimation of the deep-drawing qualities of the material when subjected to cold deformation, such as blanking,

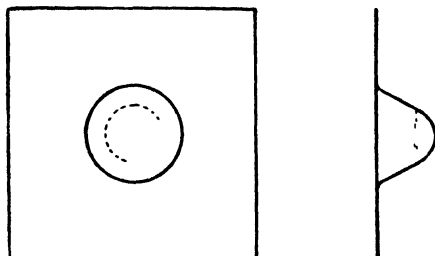


FIG. 4. ERICHSEN TEST ON 22 GAUGE SOFT SHEET BRASS

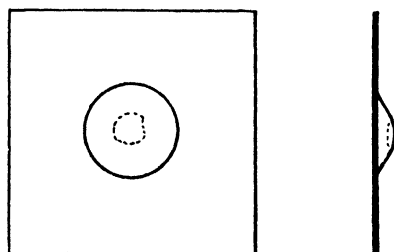


FIG. 5. ERICHSEN TEST ON 12 GAUGE HARD-ROLLED ALUMINIUM

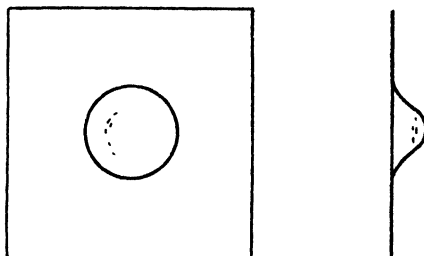


FIG. 6. ERICHSEN TEST ON 20 GAUGE TINPLATE

stamping, pressing, etc. The following are a few typical examples of different kinds and classes of sheet, varying in thickness from 26 to 21 gauge—

TABLE OF ERICHSEN VALUES AND COMPARATIVE TENSILE STRENGTHS OF SHEET METALS

Material	Erichsen depth of "hump" in mm.	Tensile strength in tons per sq. in.
Dead soft, mild steel sheet .	8-10	18-20
Bright soft, mild steel sheet .	7- 9	22-26
C.R.C.A., mild steel sheet .	7-10	20-24
Soft galv., mild steel sheet .	6- 9	24-27
Soft tinned, mild steel sheet	6- 9	20-24
Soft copper sheet . . .	12-14	14-16
Hard copper sheet . . .	7- 8	22-30
Soft aluminium sheet . .	7-10	5- 6
Hard aluminium sheet . .	5- 6	12-15
Soft brass sheet	13-15	18-20
Medium hard brass sheet .	7- 9	22-26
Hard brass sheet	5- 7	28-34

The figures just given for the various materials can be taken only as being approximate, as any variation in the analysis of the metals, temperature, and period of annealing, degree of cold work done on them, etc., will cause considerable variation both in the Erichsen value and also the tensile strength. Particularly is this so in connection with steels, as these vary so enormously in their composition, method of rolling, and annealing; and even in sheets which are supposed to be of uniformly cold-rolled, close-annealed (C.R.C.A.) quality, considerable variation will be found in both the depth of dome set up in the Erichsen machine and also the tensile strength.

Sheets are very often tested by being subjected to a bend test which consists of fixing a strip in a pair of

grips or vice (Fig. 7), and bending it first to the left through a right angle, then back through two right angles, and so on backwards and forwards until it breaks, the degree of toughness being measured by the number of right-angle bends through which the sheet has passed before breaking. For this test to be of any real value, care must be taken to ensure that the sheet at the line of bending shall be bent in each case to

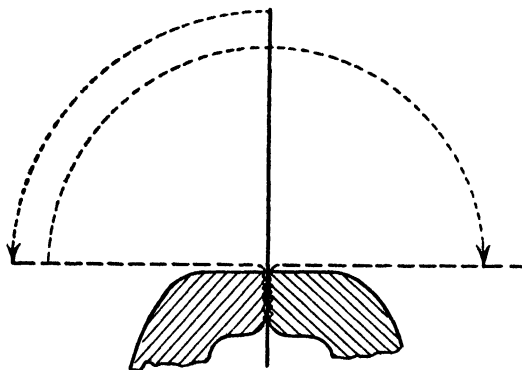


FIG. 7. SHEET METAL BENDING TEST

exactly the same radius, as the strain in the material at the heel of the bend is inversely proportional to the radius of curvature. This will readily be seen from the consideration of the statements made in connection with Figs. 8, 9, and 10.

BENDING STRAINS IN SHEETS AND PLATES

When a sheet or plate is bent or curved in any form the outer surface will always stretch or lengthen whilst the inner surface will be compressed and, in consequence, become shorter. It is worth while considering what happens when a plate is curved into the form of a cylinder, as shown in Fig. 8. Seeing the outside surface lengthens and the inside shortens, there

must be some part of the plate which neither lengthens nor shortens, and this is usually taken as the centre line of the thickness ; it is not quite true, but for all practical purposes it is sufficiently accurate. Thus in Fig. 8 the length of the plate in the flat before rolling into the cylinder would be the length of the neutral circle shown

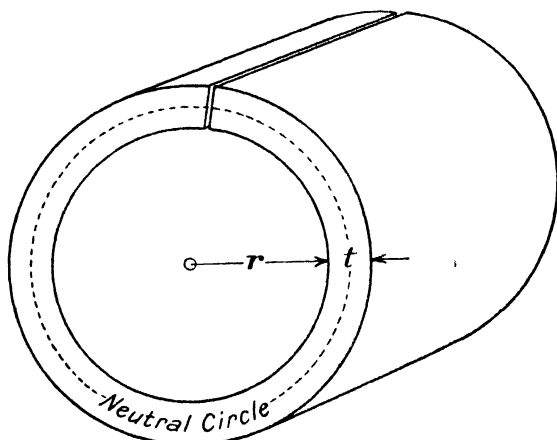


FIG. 8. SHOWING NEUTRAL LINE WHEN PLATE IS BENT INTO A PIPE

by the dotted line. The length of this neutral circle will, therefore, be

$$2 \pi \left(r + \frac{t}{2} \right)$$

whilst the length of the outer skin will be

$$2 \pi (r + t)$$

Deducting the length of the neutral circle from the length of the outer skin it will be seen that the difference equals πt . So that for every diameter of pipe and thickness of metal the length of the outside will be greater than the length in the flat by 3.1416 times the

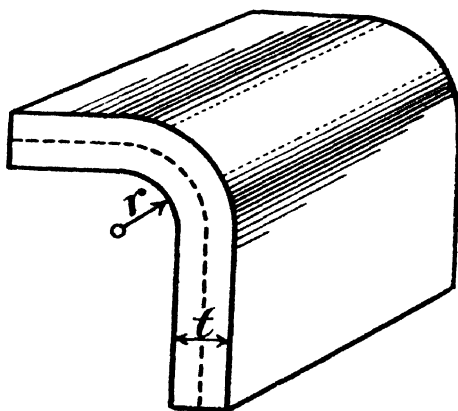


FIG. 9. SHOWING NEUTRAL LINE WHEN PLATE IS BENT TO FORM ROUNDED CORNER

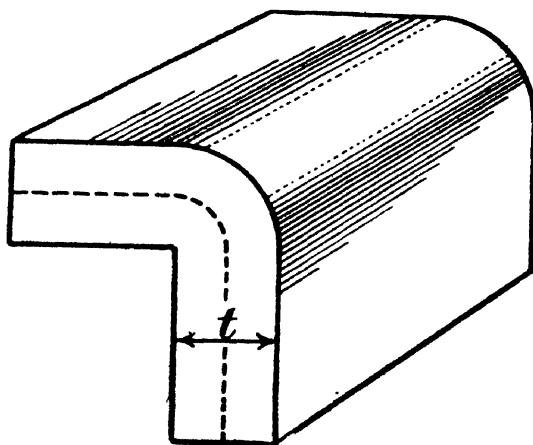


FIG. 10. SHOWING NEUTRAL LINE WHEN PLATE IS BENT TO A SHARP RIGHT ANGLE

thickness of the metal. Or, if π be taken to equal $3\frac{1}{2}$, then the difference in the lengths in the flat and the outer skin when rolled into the cylinder will be equal to the thickness of the metal multiplied by 22 and divided by 7.

It is particularly important to take notice of the fact above stated, that the difference between the length of the plate or sheet in the flat and the outer skin when it is rolled into the cylindrical form is always the same, and this explains the reason why sheets or plates which are bent through a sharp curvature are more severely treated than those bent to a larger radius.

Where a plate is bent with a rounded corner to a right angle, as shown in Fig. 9, the increased length of the outer skin will, from what has been before said, be equal to

$$\frac{\pi t}{4} = .7854t$$

This again will be exactly the same for the plate when bent to a perfectly sharp inside right angle, as shown in Fig. 10. Now the latter kind of bend will, of course, be much more severe on the plate than the former, due to the fact that the actual amount of stretch upon the bent surface will have had to take place over a very much shorter length. Perhaps the best way to appreciate this is to give a few calculations showing the actual percentage increase in length of the back of the plate when bent through different radii. The percentage increase will equal

$$\frac{100\pi t}{4} \div \frac{\pi \left(r + \frac{t}{2} \right)}{2} = \frac{100t}{2r + t}$$

If in the formula given we substitute a few values for r , the results will be as shown.

When $r = 2t$ increase in length of skin = $\frac{100t}{5t} = 20$ per cent.

[illegible]

When $r = \frac{t}{9}$, " " " " = $\frac{100t}{9t} = 50$ per cent.

. When $r = 0$ „ „ „ „ $= \frac{100t}{t} = 100$ per cent.

It will thus be seen that as the curvature of the bend becomes more acute the percentage increase along the back of the plate becomes more severe until, when the radius of curvature is equal to nothing, i.e. is bent perfectly sharp to a right-angled bend on the inside, the actual length of the back of the plate is increased by 100 per cent, i.e. it is actually stretched to twice its original length. This then accounts for the fact of a very sharp bend much more severely punishing the metal than one which is curved to a larger radius.

In connection with the bending of plates and sheets, it might also be called to mind that the stretching of a sheet or plate in the cold is really the performing of a very severe form of cold work on the material. This consequently tends to harden the metal, and make it much more liable to fracture than that portion of the plate or sheet which has not been bent.

THE TESTING OF PLATES

Thick plates which have to be used for boilers or other form of pressure vessel are usually tested by making special specimen pieces which can be put into a tensile testing machine and stressed up to the point of fracture. In determining the quality of the plate, the tensile strength, the amount of elongation, and the reduction of area at the point of fracture, are taken into account. Heavy plates also are sometimes tested by cold bending.

The actual analysis of the metal is, in many cases, specified, but even this in itself does not indicate everything with regard to the property of the plate. For a plate may have good physical properties and yet, under certain conditions, very rapidly fail when exposed to corrosive influences. In this latter case the failure of the plate through corrosion can often be attributed to the metal not having been properly made in the first instance, and may be containing myriads of small non-metallic inclusions or gases dissolved in the metal.

Finally, in the testing of metals it should be said that all the tests applied should have regard to the purpose for which the metal is to be used, for it is certainly uneconomical to apply very rigid and meticulous tests to a metal which has got to be used for some purpose in which there will be no need for any of the severe enactments which may be called for in the tests. On the other hand, where sheet or plate metals are to be used for very important purposes, the greatest care should be taken to see that they come up to the standard of requirements suitable for the conditions of service.

THE MAKING OF JOINTS

Joint making covers, perhaps, some of the most important work which has to be done by a sheet- or plate-metal worker, as the best shaped article may be entirely spoilt by an ill-formed or badly-made joint. In the making of joints several points should be clearly kept in view, such as—

1. To make a joint sufficiently strong in any form of vessel to resist the bursting pressure which may be set up by a liquid or gas.

2. The making of a tight joint to withstand the passage through it of water, steam, air, gas, or any form of liquid.

3. To make a well-shaped joint that shall not detract from the general appearance of an article.

4. To make a joint which, from the point of view of economy, is best for the purpose for which the article is to be used.

5. To make a riveted joint without the plates being in a condition of strain through want of alignment in the holes or drifting.

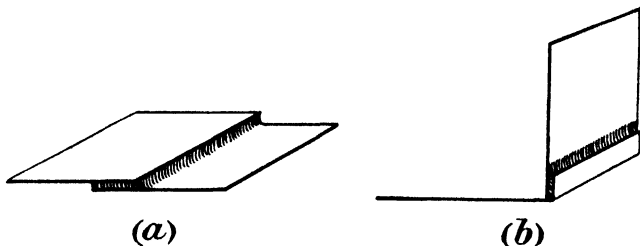


FIG. 11. SOLDERED JOINTS

6. To make a riveted joint that will stand up the greatest length of time without showing any tendency to "weeping" or leakage.

7. To make a welded joint to have maximum strength and toughness and without porosity.

SOLDERED JOINTS

The simplest form of soldered joint is that in which the sheet, tinplate, zinc, galvanized iron, etc., is lapped over and soldered as shown in Fig. 11(a). Or, where one part, such as the bottom of an article, is just edged over, slipped on to the body and soldered as shown in Fig. 11(b). Whilst the making of soldered joints such as those described is an extremely simple matter, some care and a good deal of experience are required before an operator can make a very neat joint, and one which has also maximum strength. To do soldering work efficiently means having a proper soldering bit and keeping it in good order.

SOLDERING IRONS

As everybody knows, these are made of copper, but why they are made of copper is not so generally known. The usual answer to the question "Why is a soldering bit made of copper?" is, "Because it holds the heat." This is an extraordinary misconception, as it is exactly opposite to the real reason why copper is used in the making of soldering irons. The choice of the metal copper for the purpose mentioned is because in the first instance it is an extremely good conductor of heat, and secondly, when hot gives its heat out very rapidly instead of holding it, as is usually imagined. The copper bit then is really the source of heat by which the solder is melted and kept in a fluid condition, whilst it runs into the joint, and firmly combines with the two surfaces of the sheets which it is intended to fasten together.

On account of its good conducting properties the copper bit very rapidly takes up heat from the fire, and, conversely, very rapidly gives out this heat which is imparted to the molten solder.

In addition to being a good conductor of heat, copper itself also carries a fair *quantity* of heat (see explanation of the term "specific heat"). Copper as a metal also has the property of being readily tinned, and when in the form of a soldering bit, it retains the tin on its surface for a fair length of time. This "wet" surface of the copper assists very materially, by what is known as surface tension or capillary action, in enabling the solder to flow or be carried along in the forming of the soldered joint.

Whilst the property which copper has of readily taking a coating of tin is a great advantage, this affinity which the copper and tin have for each other is a disadvantage when the copper bit is overheated, as the

tin then quickly combines with the copper and forms a hard bronze on the surface of the bit, which is extremely difficult to file away. In all soldering work one thing is essential, and that is, that the tip of the copper bit must be kept well tinned and clean. Where two plain iron surfaces have to be soldered together it is always the best plan carefully to file and clean the two surfaces and then tin them, after which they can be soldered together in the usual method.

Soldered joints are very often spoiled by the operator using only the point of the soldering bit instead of one edge of its pyramidal end in going along the joint. If the point of the soldering iron alone is used, sufficient heat will not pass to the joint to make the solder properly run ; the result will be that the joint will readily break away on account of its only being tacked together.

The conditions for making a good soldered joint are : that the flux used, whether it is killed spirit or other material, should pass right between the surfaces which are to be joined together ; and then, with the application of a properly-heated soldering iron and the right kind of solder, that the latter should be melted and flow right through the joint, filling it up completely solid.

For extra strength, joints in sheet metal which are riveted or grooved are in addition sometimes soldered. After a joint is completely soldered care should be taken to wipe it down properly for fear of after-corrosion or staining, and this is particularly so when killed spirit is used as a flux, and, in the case of zinc and galvanized iron, where acidulated killed spirit is sometimes used, an extra precaution should be taken in washing the joint down with water in which a little soda has been dissolved.

In electrical work neither killed spirit nor acids

should be used, but resin or some other form of non-corroding flux.

If in making a soldered joint it is found that the tin will not readily adhere to the surface, there are three things, any one of which may be the cause of this. In the first place the surface may not be properly clean, and care, therefore, should be taken to see that all grease, scale, or other form of foreign matter has been entirely removed. But even with a perfectly clean surface, if old or dirty flux is used, this may be the cause of the non-combining of the tin with the base metal. It should be remembered that freshly-made killed spirit (muriate, or chloride of zinc to give it its proper name) is much more effective as a flux than a solution which has been knocking about for a long time and is polluted with dirt from a soldering iron or other sources, and also probably being converted into an oxy-chloride through being in contact with the atmosphere.

Killed spirit can be quickly made by dissolving as much sheet or granulated zinc as is required to completely kill the acid. It is not advisable to use powdered oxide of zinc for the purpose of neutralizing the acid, as the resulting solution is unsuitable for soldering purposes.

The tip of the copper bit can readily be tinned by heating it to a temperature which just shows red in a dark place, carefully filing the pyramidal tip until it shows copper bright all over and immediately dipping it into the flux solution, touching it with solder, then once more dipping it into the killed spirits. After the soldering iron is re-heated in the fire it is again usual to clean the point by either wiping or dipping it in the soldering solution, this being absolutely necessary to enable the solder to flow readily along the tip of the copper bit.

Nowadays gas and electrically-heated soldering bits are commonly used for mass work, as they save the time wasted in re-heating, and their temperatures can also be regulated to the rate at which the work is required to be done.

Soldered joints, it may be stated, are not usually put on vessels or pipes that have to be subjected to great pressure, as these are usually either riveted, brazed, or welded. But with the proper width of overlap and a well-made joint, it is surprising what great strength can be obtained from a joint made with soft solder.

SHEET RIVETED JOINTS

In some types of vessels the ends of the sheet are fastened together with simple forms of riveting as shown by Fig. 12 (a). But where a stiffer longitudinal joint is required it is sometimes joggled on the back, as shown in Fig. 12 (b), this type of joint having the advantage of being smooth or flush on the inside of the vessel, and also lending itself to being closed somewhat tighter than the simple lap joint (Fig. 12 (a)).

Joints of the types shown are usually made in sheet metal by using flat-headed rivets, placing these on a bar or mandrel, lifting the sheet over it, and by tapping with the hammer on the sheet locating the position of the rivet ; then, when it is judged to be in its correct position, drawing the point of the rivet through the two sheets by the use of a hollow punch or upset. After the rivet is drawn through, it is then hammered down just sufficiently to spread over the sheet and snapped on the top with a button set, which, of course, gives it a nicely rounded appearance.

To the uninitiated it may seem quite a lengthy process to make joints in this way, but the expert sheet-metal worker fixes rivets into joints of this form in a

surprisingly rapid manner. In making riveted joints in sheet metal some regard must be given to getting the rivets in a straight line, and also to having them equally spaced. The rivets must also be drawn through the sheet without damaging or spreading it. Care must also be taken that the rivets are not hammered over sideways, but closed down vertically.

Then, after riveting, in closing up the sheet a good deal of deftness may be exhibited in laying down the edges of the sheet without springing it. Also, if the

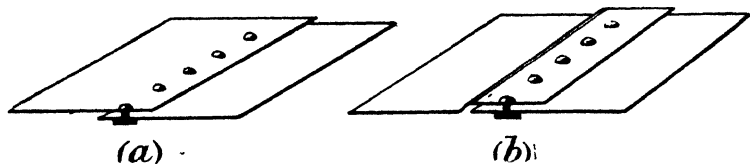


FIG. 12. RIVETED SHEET JOINTS

article upon which the joint is made is to be afterwards galvanized, there must be no bulging joints in which the molten zinc can be held and give an appearance of lumpiness.

In the making of riveted joints in sheet metal, the chief defect is usually in the form of the rivets being hammered down too much, the result being that the sheet is bulged and buckled.

In sheets of 18 gauge and thicker there is not the same difficulty with regard to buckling in the joint as with the thinner sheets, but usually in all the thicker gauges the rivet holes are punched to proper alignment and spacing, the rivets being slipped through the holes and riveted up on a bar or mandrel. In the case of thicker sheets of one-eighth and so on, snap-headed rivets are used, these being held in position by a dolly or similar holding-up tool.

Where holes have to be punched to form riveted

joints it should not be forgotten that it is just as easy to punch them in their proper positions, so that the lines of holes will come exactly over each other, as to punch them carelessly and cause a good deal of pulling to get them into position.

The riveting of light sheet metal, however, is now being rapidly displaced by methods of spot welding, as will be explained later.

GROOVED, PANED-DOWN, AND KNOCKED-UP JOINTS

These forms of joints are the commonest that are made in gauges of sheet metal ranging in thicknesses from the thinnest up to about 18 gauge, and for very special purposes also in heavier gauges. What is known as a paned-down joint is shown in Fig. 13 (a), this type of joint being used for fixing the bottoms and ends on certain types of articles, and also for jointing together pipe segments and other similar classes of work. It is also used in connection with tinplate, sheet zinc, and galvanized iron, where subsequent soldering makes it watertight.

The knocked-up joint (Fig. 13 (b)) is only the paned-down joint carried a stage further in the way of being, as its name implies, knocked-over.

In the actual making of both of the joints mentioned it will, of course, be understood that the sheets are hammered dead close together, they being shown open in the sketches for the purpose of better exhibiting the formation of the joints. The knocked-up form of joint is used in connection with all kinds of sheet metal work, and when properly made is a very effective form of jointing, it being possible to make it watertight without the aid of soldering or other methods of sealing.

In making a knocked-up joint care should be taken to see that it is quite solid on the bar, stake, or mandrel before efforts are made to turn it over, as it is only in this way that a shapely solid joint can be made. Bad joints are very often found on the bottoms of cylindrical or conical vessels in which the edge on the body sheet has slipped out of the knock-up. This defect is caused

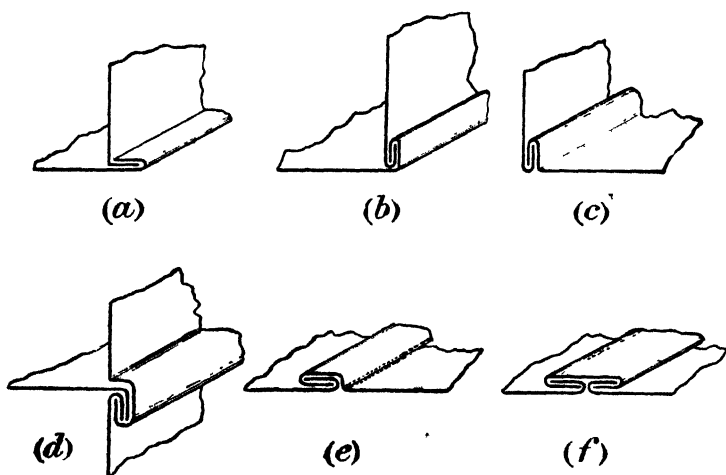


FIG. 13. PANED-DOWN, KNOCKED-UP, AND GROOVED JOINTS

through the bottom being fitted on too loosely, or the supporting bar not being dead up to the article on the inside of the joint.

Where a knocked-up joint has to be worked over either a riveted or grooved seam, care should be taken to see that the bottom of the latter is properly notched so as to avoid any form of lump in the knock-up. Badly formed joints through this cause are not only unsightly, but are sure to leak if tested with water before soldering. Also, in fitting on bottoms to circular or oval articles, thought should be exercised to see they

are not fitted too tightly, as this may cause bulging of the vertical seams, or, in the case of grooves, their being forced asunder.

Where a sheet metal is too hard to form a knock-up without splitting the sheet, the material should be properly annealed before it is edged over in the first instance.

A form of knock-up for jointing on the inside of an article is shown in Fig. 13 (c), the object of putting the joint on the inside being to keep the outer corners of the article quite flush and smooth. A joint such as Fig. 13 (c) is best made by first bending the edges to the shape shown in the sketch, slipping them together, then carefully closing them down on a bar or other convenient tool.

Fig. 13 (d) is a kind of knocked-up joint that is used when three edges of sheet have to be firmly fastened together. In this kind of joint, as with Fig. 13 (b), it is first shaped in the form of a paned-down joint, the four thicknesses subsequently being closed down to the inside sheet. This type of joint can be used either in connection with square or round articles, but in a round article it will be seen that the width of the throw-off is rather considerable, necessitating a flange of about half an inch to five-eighths of an inch wide, depending upon the thickness of the material. In throwing-off, or stretching this flange, as it is sometimes called, it is always advisable not to punish the sheet too much before annealing it, and in any case every care should be exercised to avoid having anything in the form of a crack or split in the joint.

Fig. 13 (e) is the common form of groove which is made by folding over two edges, hooking them together, then closing down with a groover, subsequently hammering the groove closely together either by a mallet or hammer, depending upon whether the

material is thin or heavy sheet. In making a grooved joint the right width of groover should be selected to suit the right size of edge that is being turned over, as a groover which is too narrow will tend to cut the edge of the sheet at the groove almost through, whilst if the groove is too wide in the groover it will form a rather slack groove.

The main thing in making a grooved joint is to see in the first instance that the edges of the sheet are cut as straight as possible, and that the fold turned over is also straight. If this is not done there is a danger of the groove being open at some part of its length, in addition to which it will be quite unshapely.

Fig. 13 (f) is a type of double-groove which can be used in 13 to 16 gauge sheet, where a seam of this description is desired. In this case it hardly need be mentioned that the upper part of the groove is a separate strip which is slipped over the two edges at the bottom, the whole then being hammered close down, the strip really forming a kind of butt strap.

Whether the mallet or hammer should be used on a groove depends upon the kind and thickness of the sheet, and the type of finish required. In any case, where these two tools are used the greatest care should be taken to see that the marks of the tools are not left on the surface of the metal, this always being a sign of poor workmanship.

In certain classes of repetition work both grooves and knock-ups are rapidly put on by machinery, but there is and always will be a large amount of sheet metal work required in which the various joints will have to be made by hand.

BRAZED JOINTS

These are made in all kinds of sheet metal. When properly made they have the advantage over either

soldered or grooved joints inasmuch as they are stronger, and when a vessel is to be used at a high temperature they will stand up against this much better than a soldered joint.

In certain classes of sheet iron work it should be noted that the acetylene welding of joints has in a large measure taken the place of the brazed joint. Also, where in times past tubes were formed out of sheet and the seams formed by brazing, in many cases now tubes are drawn or rolled out of the solid and are, therefore, seamless. However, there is still a certain quantity of work required to be done in which it is essential that brazed joints should be formed. The metal worker, therefore, who aspires to have a good working knowledge of the manipulation of metals, should learn not only how to braze, but to make a brazed joint with a 100 per cent efficiency. This can, of course, only be done by forethought followed by a fair amount of practice.

In commencing to learn brazing the best plan is to start by experimenting on the jointing of sheet iron or mild steel, as with these metals there is not the same need to be so careful in cleaning the surface or regulating the temperature.

The simplest form of joint is the wedge or scarf type shown in Fig. 14 (a). In this the two edges of the metal are thinned down as shown on the sketch, the length of the tapered portion being equal to about four times the thickness of the metal. There can be no hard and fast rule for the length of the wedge, except that it should certainly not be less than twice the thickness of the metal. If the wedge is too short the brazed joint may break through the brazing spelter. If the wedge is too long it becomes increasingly difficult to ensure that the spelter has completely covered the two inner surfaces of the joints; consequently, there will be danger of leakage or bursting of the joint.

The writers have carried out a large number of experiments on the strength of brazed joints, and they have found that where the wedge type of joint is made

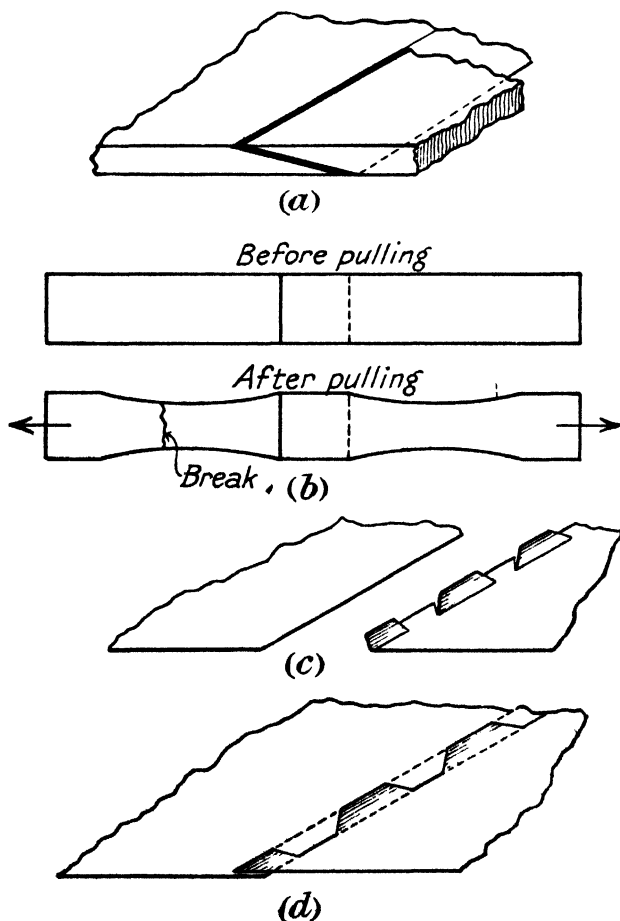


FIG. 14. BRAZED JOINTS

and is solidly brazed, a joint made in mild steel will never break at the braze if the overlap is at least three times the thickness of the sheet or plate.

Test pieces were made as shown in Fig. 14 (*b*), these being placed in a tensile testing machine and pulled until fracture took place. When the joint was properly made it usually broke as shown in the sketch, the plate becoming thinner and narrower at the points shown. It will be observed on the sketch that the part of the bar at the brazed joint retains its full width, this being due to the fact that where the metal is brazed either in sheet iron or copper it tends to be somewhat harder and stiffer at the joint. This defect can be overcome to some extent where necessary by mild annealing after brazing.

In carrying out the series of tests it was discovered that where fracture at the joint took place it was invariably due to the brazing spelter not passing between the surfaces of the metal, and therefore leaving the joint hollow at those parts. In steam-pipe welding this is one of the points which should be very carefully watched. Examination of fractured brazed-copper steam pipes has shown that the joints invariably gave way at the parts where the brazing had not been properly done.

In making a good solid brazed joint, particularly in copper or brass, the essential thing in the first instance is cleanliness of the surfaces to be united together, then before any attempt is made to heat the joint, a flux solution of borax water should pass completely through it. This should then be followed by the application of the brazing paste which is made up of borax, finely-divided brazing spelter, and water. The heat in the first instance should be applied generally so as to drive away the mixing water and the water of crystallization without unduly disturbing the resulting brazing compound. The application of further heat will result in the melting down of the borax and the spelter.

The heat should only be applied sufficiently long to allow the spelter to run completely through the joint, so as effectually to unite together all parts of the opposing surfaces. Additional heat or a higher temperature applied to the joint will only result in the breaking down of the brazing spelter and the spoiling of the joint. If during brazing the spelter tends to run dry, a little powdered borax should be dusted over it.

After cooling, careful hammering can be applied to the brazed joint, whether it be in copper or iron, as this breaks away the spent borax and should leave the joint quite clean.

The ends of steel band-saws can be brazed together by the scarf-joint method, but great care has to be taken to see that the saw is in proper alignment, and that it is not overheated at the joint; indeed, in the case of small saws the brazing can be carried out by the heat which can be applied by the red-hot jaws of a pair of tongs. It is necessary subsequently to temper the band-saw at the brazed joint, or else it will inevitably break at this part.

A brazed joint can be formed in light sheet metal by first of all cutting one edge of the sheet to form cramps as shown in Fig. 14 (c), this then being lifted up, the plain edge slipped under, and the cramps closed down with hammer or mallet as seen in Fig. 14 (d). If a joint of this description is carefully made in such a way as to leave no holes or openings at the corners of the cramps, it will be found to be quite tight before brazing takes place.

In sheet iron circular articles with a joint of this description there is no need to adopt any method of holding the two edges in position, as the sheet may be rolled to a smaller diameter than the vessel which it is to form, the two edges then being sprung together, and this will offer sufficient pressure to keep the joint

from opening during the time it is being brazed. If, however, there is any danger of the opening of the joint whilst it is being brazed, binding wires should be fastened round the article.

For articles which are made out of heavy metal a combination wedge and cramp joint is sometimes used, the cramps being cut obliquely with a knife, so that when they are hammered down no rough edge will be shown either at the joints or the two sides of the cramps.

PLATE RIVETED JOINTS

The formation of plate riveted joints for vessels which have to be subjected to high pressure liquid, steam, or gases, is an exceedingly important class of work, as the making or marring of a piece of plate work depends very largely upon the quality of its jointing.

There are a great number of riveted joints used in connection with plate work, but it will be sufficient to show two of the most important. Fig. 15 (a) shows a single-riveted lap joint, whilst Fig. 15 (b) shows a section of a double-riveted lap joint.

The width of overlap for a single-riveted joint is usually taken to be equal to three times the diameter of the rivet; thus, if rivets are $\frac{1}{2}$ in. diameter, the overlap will be $1\frac{1}{2}$ in.; and if $\frac{3}{4}$ in. diameter, the overlap will be $2\frac{1}{4}$ in. The diameter of the rivet and their distance apart vary for various classes of work, but, generally speaking, for $\frac{3}{16}$ in. plate, $\frac{1}{2}$ in. diameter is used; for $\frac{1}{4}$ in. plate, $\frac{5}{8}$ in. diameter; and for $\frac{3}{8}$ in. plate, $\frac{1}{2}$ in. or $\frac{3}{4}$ in. diameter is used.

Where holes are punched in the plates it is always a good plan to spend a little extra time in seeing that the holes are marked out properly, either by templet or directly on the plate, and also that they are punched

exactly at the positions so marked. A little extra care exercised in the marking and punching of plates would save a lot of time in bolting the plates into position and carrying out the riveting. In high-class work the holes are usually drilled right through the two plates in position, or, if not in position, by multiple drilling machines, which fix the holes to an exact pitch.

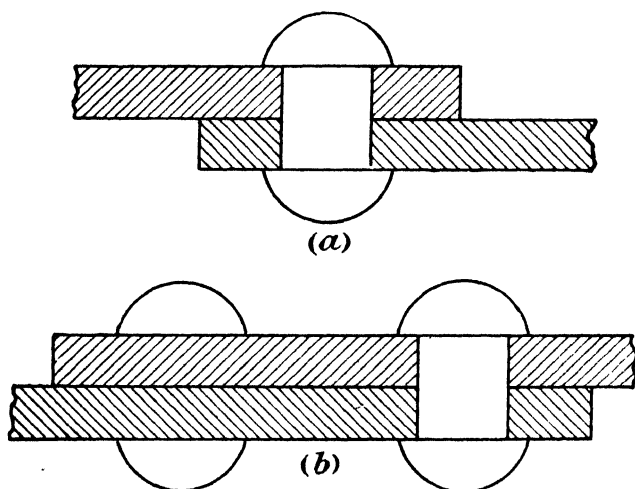


FIG. 15. PLATE RIVETED JOINTS

In all riveting care should be taken to see that the rivet holes are well filled with the rivet, and that the snap head is correctly formed without cutting of the plate around the rivet with a snap.

Edges of the plates should be caulked closely down, but the metal not hammered in sufficiently hard to cause springing of the plate. In the best class of work it is always an advantage to plane the edges of the plates at a slight bevel, as this ensures a better means of effective caulking. There are many kinds of heads and points formed on rivets, depending upon the class of work which is being carried out.

For pressure work it should not be forgotten that the best kind of single-riveted joint has a strength of less than half of that of the solid plate ; whilst a double-riveted lap joint has about 65 per cent strength of the plate ; and a treble-riveted lap joint about 80 per cent strength of the plate. Any defect in these joints in the way of wrong diameter of rivets, or wrong pitch, will reduce their efficiency. Or, if the work done in punching, drilling, and riveting is not of the best, the efficiency of the joint will also be impaired.

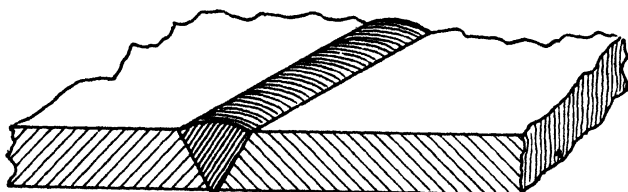
WELDED JOINTS

Joints in light sheet metal are now very often made by the oxy-acetylene process, in which a very small blowpipe is used which just fuses down the two edges of the metal, effectively welding them together. Plates and bars are also welded by the oxy-acetylene process, blowpipes of the right calibre being used to suit the thickness of the plate ; such a joint is shown in Fig. 16 (a). The same type of joint is also made by the electric-arc welding process. Where a particularly strong joint is required double welding is sometimes carried out as shown by Fig. 16 (b), the strength of the joint being practically equal to that of the plate.

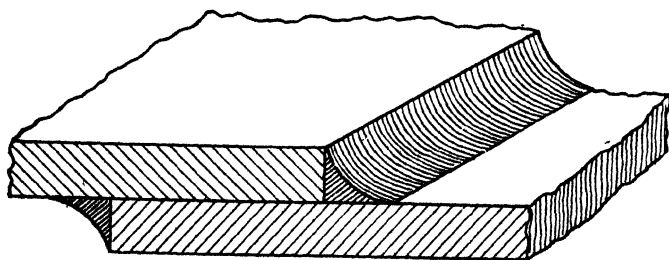
There are a great number of designs of joints which are used both in connection with oxy-acetylene and electric-arc welding, and those who are interested will find these set out in *Electric-Arc and Oxy-Acetylene Welding*, published by Sir Isaac Pitman & Sons, Ltd., London.

Heavy plate work, such as galvanizing baths and similar articles, has edges and corners welded together, either by the fire process, or more commonly by the use of water gas ; the heating and welding being carried out by treating short lengths or sections at a time, until the complete joint is formed.

Sheet metal pipes and other types of sheet metal work which is required to be done in bulk is very often joined by the method of spot welding, this taking the place of hand riveting. Spot welding of sheet metal is really a form of putting in what one might call dummy rivets, the two sheets being welded together at small



(a)



(b)

FIG. 16. PLATE WELDED JOINTS

areas as shown in Fig. 17 (a). The heating current is applied to the joint by means of two copper electrodes, sufficient heat passing through the sheet from one electrode to the other to almost melt the iron, and, as the electrodes exert a little pressure upon the sheet, this is sufficient to bring the two inner surfaces into close contact to weld them together.

Seam welding by the method of electricity is shown in Fig. 17 (b), in which the edge of a sheet is turned

over to form a bead as with bicycle wheel rims, then effectively welded down by running the edge through two copper wheels which act as electrodes for the supply of the necessary welding current.

Hoops and strips which form tyres and similar articles are sometimes butt welded together (Fig. 17 (c))

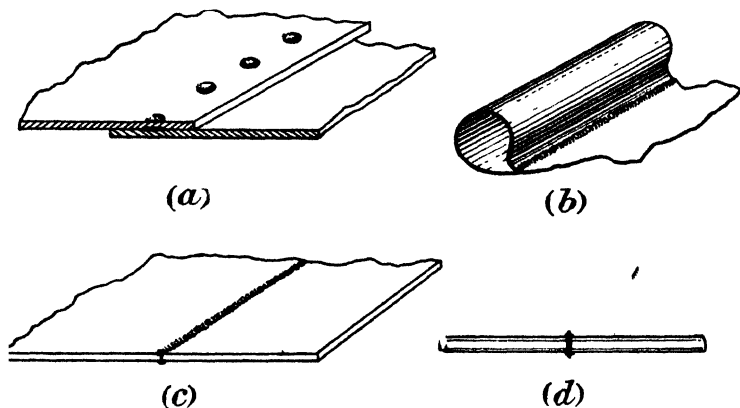


FIG. 17. SHEET AND WIRE WELDED JOINTS

by the resistance method of welding, the two edges of the strips being closed up with pressure after they have been slightly fused or melted.

Wires to form rings which may be used in connection with the beading of sheet metal work are welded together by the resistance method of welding as shown in Fig. 17 (d).

Certain defects sometimes develop in connection with the welding of sheet metal, and before the operator is blamed the material being welded should be carefully examined. High sulphur in steel is a great deterrent in connection with the formation of a strong welded joint. Also, the presence of an undue percentage of carbon and phosphorus does not lend itself to the making of the best type of welds.

WIRING, CREASING, MOULDING, AND SWAGING

The edges of circular and flat-sided articles are very often turned over, and a wire inserted to form a bead, which not only gives strength to the sheet, but adds considerably to its appearance. The quickest form of wiring is that which is carried out on the flat sheet, this being done by first of all turning up an edge, either by machine or hand, then inserting the wire, and closing the sheet down on it with a mallet. The edge of the sheet is then tucked in either by machine or by hand, as the case may be.

For wiring to look well, the edge of the sheet should not only be turned over evenly, but closed down regularly on to the wire, taking care that sufficient allowance has been made on the sheet to just completely cover the wire. Uneven wiring causes unsightly lumps and hollows on the top edge of an article. It is extremely important that the corner of the sheet shall be properly notched as shown in Fig. 18 (a), the allowance being such that when the two folded edges, shown in Fig. 18 (b), are hooked together the two ends of the wiring shall just butt together. Also for a neat job it is usual to let the wiring in as shown in Fig. 18 (c).

For common work it is quite sufficient to have one straight cut across the corner to form the notch, instead of two as shown in the sketch. For all neat work it is important that neither bulges caused through overlapping with too small a notch, nor openings caused through too large a notch, shall be exhibited on the work.

Sometimes "false wiring" is made by forming the wire edge around a straight wire, then pulling the latter out, which leaves hollow wiring, as shown in Fig. 19 (a). A similar class of work is also carried out

by knurling machines, which form the hollow or "false" wiring directly without the use of the pulling-out wire.

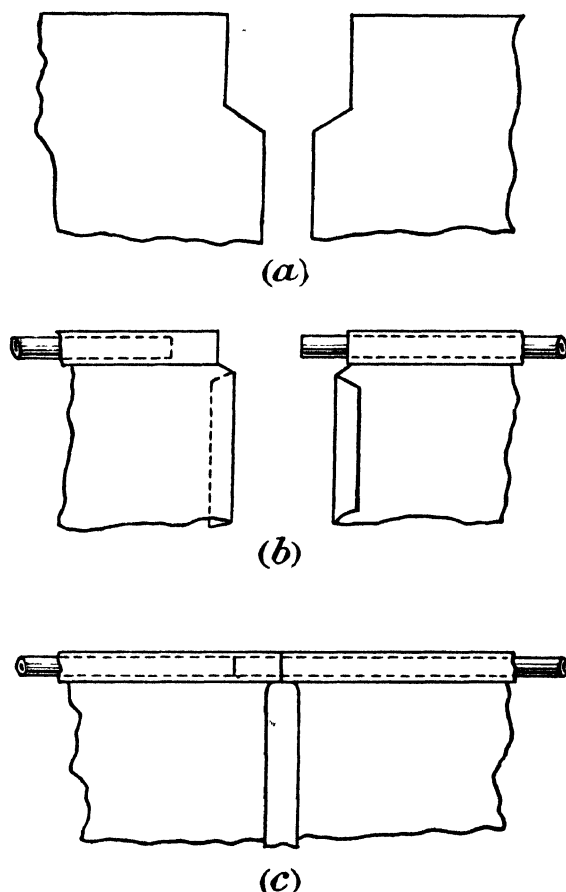


FIG. 18. DETAILS OF WIRED AND GROOVED JOINT

A form of wiring known as "creasing," shown in Fig. 19 (b), is very commonly done on certain classes of work. After the edge of the sheet is wired in the usual

way, it is then put over a crease in a creasing iron and driven down into it by the aid of a mallet or press, forming a reverse wiring. For large straight work the

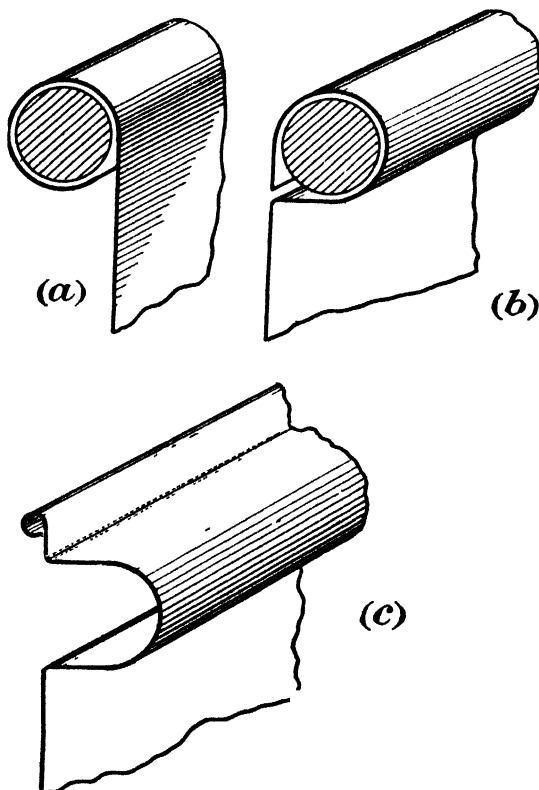


FIG. 19. SHEET BEADING AND MOULDING

wire or bar is usually pulled out after the moulding is formed, which, of course, leaves the edge hollow.

Moulding for trunks, boxes, etc., such as is shown in Fig. 19 (c), can be made by hand by bending around a bar, or for quick work can be formed in a press, or, as is sometimes done, by the use of a pair of special

moulding wheels in a swaging machine, the mould being formed by gradually increasing the depth by closing up the pair of swaging wheels. In boxes, this kind of mould is jointed at the corners either by a cap or knee, or a mitre can be formed on the sheet, and the inside of the mould filled up fairly solid with solder.



FIG. 20. SHEET METAL SWAGING

The surfaces of articles are swaged to give them either stiffness or ornamentation. One such design of a swage is shown in Fig. 20, but these are usually formed to suit the taste of the designer for the kind of article made. As with box moulding, swaging is carried out by suitable wheels fixed on a swaging machine.

HOLLOWING, RAISING, DRAWING, AND SPINNING

In hand work the hollowing of sheet metals is done by the aid of a suitably-shaped hammer and a block of timber having hollows of various diameters and depths cut in it. Care should be taken in sinking the metal to see that no part of it crinkles or overlaps at the edges. In dishing circular articles it is usual first of all to hollow round the edge, then gradually work inwards to the middle. Some judgment must be exercised as to the depth the sheet can be taken down before requiring annealing. After some practice, the operator soon finds about how far any kind of sheet metal can be worked without danger of it splitting or cracking.

The size of disc for a hollow bowl, as shown in Fig. 21, can be found by setting out a right-angled triangle, taking half the diameter for one side and the depth for the other, the third or slant side giving the radius of the disc which will work up into the required bowl. Or the diameter of the required circular sheet can be

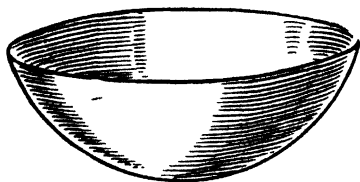


FIG. 21. HOLLOWED BOWL

obtained by calculation from the following rule—

“To the square of half the diameter add the square of the depth and extract the square root of the sum.”

Thus, if a bowl be 8 in. diameter and 3 in. deep, the radius of the disc will be equal to

$$\sqrt{4^2 + 3^2} = \sqrt{16 + 9} = \sqrt{25} = 5 \text{ in.}$$

Or, to give another example, assuming the diameter is 12 in., and the depth 5 in., this will work out to

$$\sqrt{6^2 + 5^2} = \sqrt{36 + 25} = \sqrt{61} = 7.8 \text{ in.}$$

The disc so obtained will have an area which will be exactly equal to that of the area of the curved surface of the bowl, so that in working the metal care must be exercised to see that it is hollowed uniformly, or else it may be too small on the one hand or too large on the other.

In hollowing plate metal, where a number of articles are required of one shape they are formed from the red-hot plate in the hydraulic press, but where only one or two plates are required to be shaped, these are worked in a cradle or a cast iron hollowing block, if one happens to be at hand.

“Raising” differs from hollowing inasmuch as the metal is usually worked over a head or other form of tool, it being gradually brought to the required shape

by the aid of the mallet and stretching hammer. In raising, like spinning, the thickness of the metal is better maintained than in the case of hollowing.

Sheet metal is "drawn" to cartridge and other shapes by having suitable press dies by which the sheet metal is gradually taken from the blank through the various shapes, as shown from left to right in Fig. 22. Similar operations obtain whether the article is small or large, but in cases where the shape demands a shoulder, narrow neck, collar, or flange, special dies

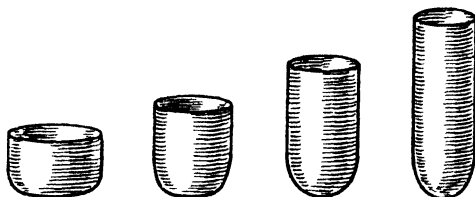


FIG. 22. DRAWING OPERATIONS

are used in the finishing stages. It might also be mentioned that where narrow strip sheet is required to be formed into a mould in long lengths, this is done by drawing the strip through suitably shaped dies; also small diameter sheet metal butt-jointed tubes are formed by drawing the sheet through dies suitable for the purpose.

Where a large number of hollow articles are required, these, if of small size, can be shaped by a pair of dies in a fly-press of requisite power.

The spinning of sheet metal is done on a special form of lathe with tools specially made for the purpose. It really means that circular articles are hollowed, raised, or the edges turned over by rotating the sheet metal which is attached to a wooden chuck on a lathe head, and by the exertion of requisite pressure by a tool of the correct shape. Although a special simple form

of lathe is used, metal spinning can be done on almost any kind of lathe if it is adjusted for the purpose.

The simplest form of spinning is that in which the lid and rim of a saucepan cover are connected together. In this case the hollowed top is fastened to the chuck and a pressure tool with a small grooved wheel at the end brought in contact with the edge of the cover. This is gradually turned over, the rim being slipped in, and the edge then being closed down. Various shaped wooden chucks are used to suit the formation of all kinds of articles, and the hand pressure tools are of such a shape as is required to press the sheet metal gradually on to the chuck.

The expert spinner can turn out some very beautiful work, but in these days of rapid production with all kinds of presses, stamps, etc., there is not a great field for metal spinning other than for finishing work or to satisfy the ambition of the amateur.

STAMPING AND PRESSING

Heavy sheet metal articles in quantities are usually formed either in the cold or hot state by drop-stamping, the bottom die usually being of cast iron or steel, whilst the top die may be of lead covered with a plate of sheet steel of the shape required. Where a great quantity of repetition work is needed the top die may be of steel.

For straight lengths, such as sheet metal gutters, ridge caps, and similar classes of work, an eccentric press is used in which a large number of interchangeable dies may be fixed to form many patterns of mouldings or other kinds of work.

The fly or power press is also commonly used for cutting out shapes in sheet or plate metal. The success of this class of work depends very largely upon the character of the dies. A good, sharp, clean-cut edge

should be aimed at in the plate which is being pressed, as a burr on the edge of the plate is very objectionable, particularly if the latter is required to be bent or otherwise shaped. A burr on the edge of a plate which is to be bent is also one of the most fruitful sources of the commencement of fracture from the edge of the plate inwards.

STRETCHING AND FLANGING

A narrow flange on cylindrical or conical sheet metal articles is usually turned over by the aid of a spinning jenny, but where a flange is of considerable width it is necessary to work it over gradually on a bench head with a round-nose stretching hammer, as by this means the edge of the metal is lengthened and consequently avoids fracturing. To stretch a flange over neatly without breaking the metal requires a good deal of practice and some judgment as to when it is necessary to submit the flange to annealing.

In heavy plate work flanges are turned over hot in machines designed for the purpose, but for odds and ends of work, where plates require flanging, it is usually done by hand on the ordinary tools or blocks which obtain in a plate-working department.

PLANISHING OR FLATTENING

The planishing or flattening of sheet iron is just one of those many jobs which the trained metal worker seems to do by instinct, but workmen who have had little experience in this class of work should commence operations on a sheet or plate by first of all examining the plate to see just where the buckles are located, and then think out how they can be removed. The plate or sheet, it might be mentioned, is buckled because some part of the plate is locally too long or too

short, and in the hammering or flattening this is the defect which has to be remedied.

Inspection of a sheet or plate will show that it is generally buckled along the edges, i.e. the edges are loose ; or it is buckled in the centre, which means that this part is somewhat baggy and the sides of the sheet are therefore tight. In some sheets, however, there is sometimes a combination of one half of the sheet being baggy at the middle, and the other half of the sheet tight in the middle and loose at the sides. A simple inspection will show the position of the buckles. In reasoning the matter out it will be seen that what is required to be done is to lengthen the tight portions of the sheet, and just allow the loose portions to fall flat. If the buckle is in the middle of the sheet it will be necessary to hammer along the sides, gradually tailing off towards the middle. If the edges of the sheet or plate are buckled then the centre should be hammered, gradually tailing off towards the outside.

In thin sheet work the greatest care should be taken with regard to the intensity of the hammer blows, as one or two blows which are too heavy may entail a hundred others to remove their effect. Where a straightening mangle or rollers are available it is always advisable to run the sheets or plates through these first, which, in light metal work, will have the advantage of gathering up a lot of small buckles into one, which may afterwards be readily removed by hammering ; and in the case of plates the straightening or flattening obtained by the rollers may be sufficient for certain purposes, but if extra flat plates are required a little subsequent hammering will complete the operation.

Black sheets, thin plates, and also galvanized sheets, are sometimes flattened by being stretched in a hydraulic stretching machine. The sheets are generally placed

in the machine three or four at a time, the ends of the sheets being held by special knee grips, and such a load put on as to stretch the sheet sufficiently to remove the buckles entirely.

THE "BREAKING" OF SHEET METAL

After sheet metals have been annealed there is a peculiar inter-granular stiffness set up which makes it difficult to bend the sheet round a curve without crinkling, this being particularly so with mild steel sheets. It would appear in the first instance that this has something to do with the surface condition of the sheet, but this is not so, as the crinkling occurs even when the scale has been removed from the surface. This inward stiffness, however, can be removed from the metal if it is stretched, rolled, or cold work done upon it in any other form.

Mild steel sheets or hoops can be made springy by passing them through plain rollers under sufficient pressure to cause a little inner disturbance of the grains of the steel.

Tinplates can be made elastic by passing them backwards or forwards through bending rollers.

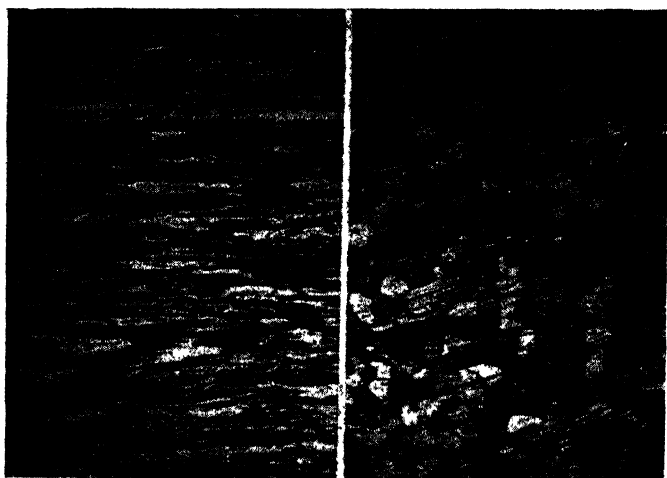
ANNEALING

It is interesting and instructive to examine the microscopic structure of steel sheets, both in the hard-rolled and annealed conditions, as these indicate the great change which takes place in hard-rolled or hammered mild steel sheet after it has been annealed.

Fig. 23 shows on the left hand the microscopic structure, to 100 diameters magnification, of a section of a hard-rolled, mild steel sheet; and on the right hand the structure of the same sheet after proper annealing. On this it will be seen that the elongated

grains have under heat treatment been re-formed into their natural shape.

Microscopic examination of metal sections forms an important part of the proper examination of a metal, and the type of photomicrograph shown in Fig. 23 is prepared by doubling the sheet of mild steel over five or six times, usually in the direction of rolling, closing tightly down, carefully filing crossways, followed



(Magnification 100 diameters)

FIG. 23. MICROGRAPH SHOWING STRUCTURE OF
ROLLED AND ANNEALED SHEET

by grinding on a fine carborundum wheel at right angles to the filing marks. From this point, polishing is carried out on successively finer emery papers (of the Hubert Superieure variety), starting with 1M grade and finishing with 00 or 000 grade, turning the sample through a right angle at each change of paper. These papers are held down on a piece of plate glass or similar hard flat surface, in order to keep the face of the specimen dead true and flat.

The final polishing, at right angles to the last emery paper marks, is done on a motor-driven disc covered



(Magnification 100 diameters)

FIG 24. ANNEALED MILD STEEL SHEET WITH LARGE GRAIN



FIG 25. BADLY ANNEALED MILD STEEL SHEET

with Selvyt cloth, moistened with water and “diamondine,” i.e. aluminium oxide, in a finely-divided state. This polishing is continued until all the emery scratches are removed and a perfectly mirror-like surface remains.

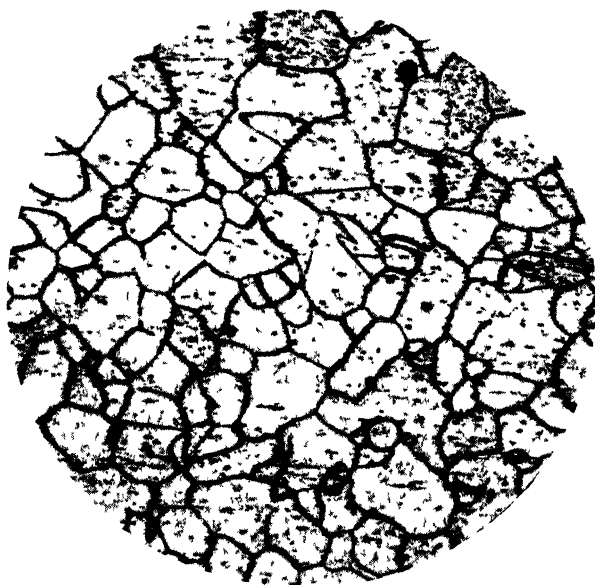
This surface, when viewed under the microscope, only shows non-metallic inclusions, cracks, etc., and has to be etched in some weak acid before the grain structure shows up. For steels, these etchants, as they are called, usually consist of a 5 per cent picric acid solution in absolute alcohol or a similar solution, using 1-3 per cent nitric acid. The samples are immersed in these solutions until the polished surface appears slightly dulled, when, on rinsing with water and wiping with a clean Selvyt cloth dipped in alcohol, the grain structure can be clearly seen under the microscope and may be photographed, if necessary, when a permanent record is required.

The grain size in a mild steel sheet may be very greatly modified by the form of heat treatment. This is well illustrated by the two photomicrographs, Figs. 24 and 25. A thin sheet of mild steel after annealing was found to be quite soft along the edges, whilst it was hard and stiff at the middle portion. Microscopic examination revealed that the temperature of annealing on the outside had been higher than at the inside, and that, therefore, the surface of the sheet was much better annealed. The type of microscopic structure exhibited on the outside is shown in Fig. 24, whilst the type of structure of the middle portion of the sheet is shown in Fig. 25, both of the photomicrographs being to a magnification of 100 diameters.

Whilst the iron of the mild steel sheet has formed the grains as shown in Fig. 24, it will be observed that the rolling structure, shown in Fig. 25, has not been altered on account of the low temperature of annealing.

Mild steel sheets which are required for working-up purposes should be annealed in such a way as to remove entirely the effects of the rolling. Two further examples illustrating good and bad annealing are shown in the photomicrographs, Figs. 26 and 27.

Where a sheet has a carbon content below about 0.10 per cent there is always danger of large grain growth and consequent brittleness, if care is not taken in the methods of annealing. Fig. 26 shows the microscopic structure, to 100 diameters magnification, of a



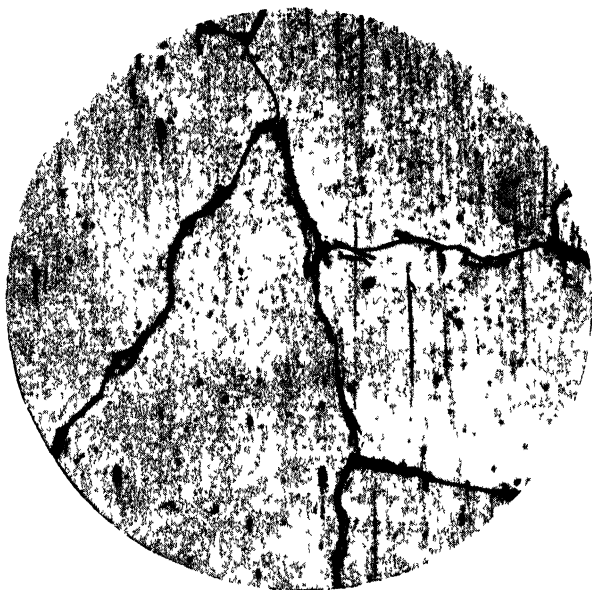
(Magnification 100 diameters)

FIG. 26. MICROSCOPIC STRUCTURE OF CORRECTLY ANNEALED MILD STEEL SHEET

mild steel sheet, which was quickly annealed at the correct temperature and allowed to cool down in the atmosphere, whilst Fig. 27 shows the microscopic structure, to 100 diameters magnification, of a mild steel sheet, the grain of which has grown abnormally large through the slow heating and slow cooling of the sheet. In structures such as that exhibited, it will be seen that the carbon has collected at the grain boundaries in the form of the brittle compound known as

cementite or carbide of iron. Sheets with a structure such as that shown will readily fracture when bent or otherwise pressed.

As showing the comparison between mild steel and charcoal iron, Fig. 28 represents the microscopic struc-

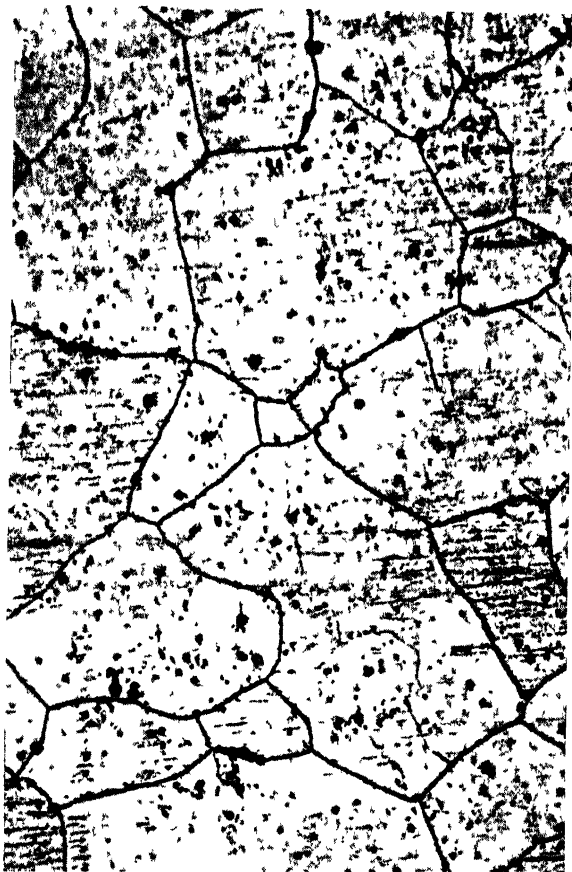


(Magnification 100 diameters)

FIG. 27. MICROSCOPIC STRUCTURE OF OVER-ANNEALED
LARGE GRAIN MILD STEEL SHEET

ture, to a magnification of 150 diameters, of a section of Swedish charcoal iron. It will be observed that the low carbon mild steel and the charcoal iron are of very similar structure, except that the latter shows no carbon at the grain boundaries. The small black specks in each of the photomicrographs, it might be mentioned, are either small non-metallic inclusions in the iron, or pits from which these have been dissolved away by the weak acid etching medium.

In connection with annealing, it is also worth while mentioning that the size of grain induced in the anneal-

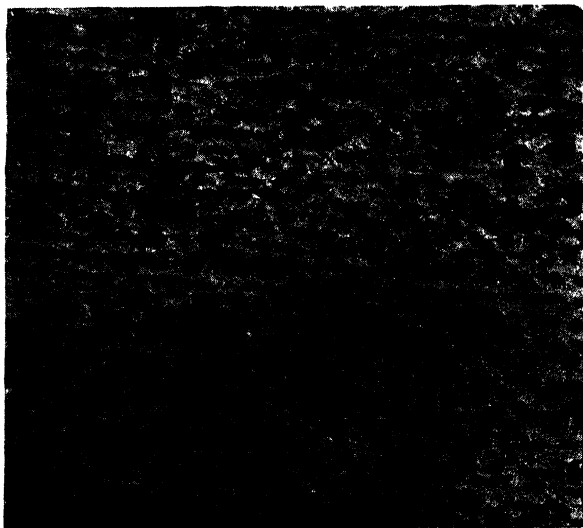


(Magnification 150 diameters)

FIG. 28. MICROSCOPIC STRUCTURE OF SHEET OF SWEDISH CHARCOAL IRON

ing in some measure depends upon the amount of cold work which has been done upon the sheet. If the sheet has been subjected to only a small quantity of cold

work, then the grain size will be large if the ordinary temperatures of annealing, about 700 to 750° C., are applied. But with a lower temperature of about 600° C. it will be found that the steel has a smaller grain, and will, consequently, be tougher. If, however, a large quantity of cold work has been done on the



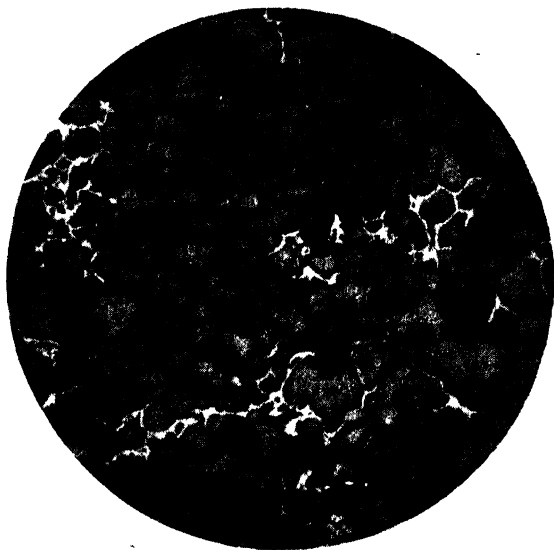
(Magnification 100 diameters)

FIG. 29. PHOTOMICROGRAPH SHOWING THE ROLLED STRUCTURE OF BOILER PLATE

sheet or plate, such that its cross-sectional area has been reduced by about 25 per cent, it will be found that a small grain structure will be induced even with the ordinary temperatures of annealing. It might also be noted that if a high temperature of annealing, say 900–1000° C., is applied, then again the grain size will be very large and similar to that shown in Fig. 27.

In a red-hot sheet or plate the grain size can be very quickly refined or reduced by rolling or hammering

whilst the metal is at a high temperature. In boiler plate, which contains carbon of about 0·25 per cent, the rolled structure is usually in the form as seen in Fig. 29, this being a photomicrograph to a magnification of 100 diameters. As mentioned before, the black areas show the disposition of the carbon in the form of what



(Magnification 100 diameters)

FIG. 30. MICROSCOPIC STRUCTURE OF BRITTLE, HIGH PHOSPHORUS, STEEL SHEET

is known as pearlite, whilst the white streaks show that part of the metal which is practically pure iron. By suitable annealing the rolled structure can be entirely broken up.

Sometimes sheets which contain as much as 0·14 per cent or more of phosphorus are exceedingly brittle when they are bent; the structure of such a sheet is shown in Fig. 30, to 100 diameters magnification, where the phosphorus can be seen in the form of

phosphide of iron in the patches of white network. As this network is exceedingly hard and brittle it can be readily understood why mild steel sheets containing the amount of phosphorus mentioned fracture when subjected to bending. Both copper and brass sheet can be annealed if heated to a blood-red colour and allowed to cool out in the atmosphere, but copper after heating is often plunged into water which removes the oxide from its surface, and particularly is this so if a little common salt is sprinkled on the sheet before it is plunged in the water.

Sheet zinc can be very considerably softened, particularly in winter time, if it is warmed in front of a fire before being edged, folded, hollowed, or otherwise worked.

ACIDS USED IN SHEET METAL WORK

Where it is required to clean the scale from the surface of sheets the various mineral acids are used. Hydrochloric acid is commonly used for pickling or cleaning the scale from the surface of mild steel, as it has the advantage that it can be used at a comparatively low temperature. Various strengths are used, but usually a cistern for cleaning sheet iron is made up from 14 to 20 degrees on the Twaddell hydrometer.

Sulphuric acid is also used in the cleaning of mild steel sheet, but with this it is necessary to have it heated by steam or other means to a temperature of about 80° C.

For special cleaning, a nitric acid dip is sometimes made up. When articles are covered with grease, this can be first of all removed by one of the now common forms of degreasing plant, followed by a hot caustic-soda solution dip. If the cleaning is to be followed by any form of coating, such as galvanizing, tinning, or electro-plating, it is essential that a chemically clean

surface shall be obtained if a coating of good quality is to be produced.

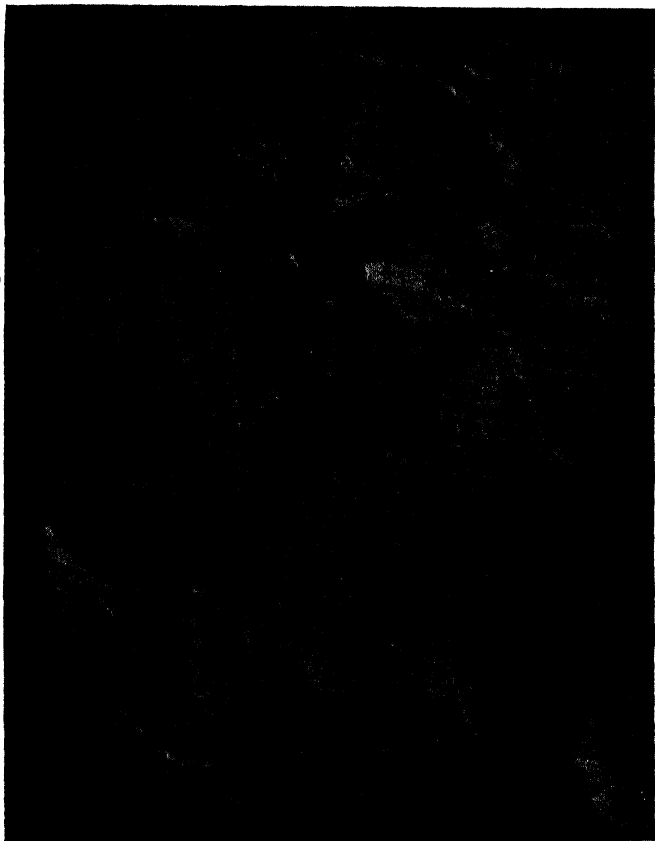


FIG. 31. SPANGLES ON GALVANIZED SHEET
(*Natural Size*)

Where an article is to be galvanized after it is manufactured it is essential that, whilst the surface of the sheet is properly clean, care be taken that it is

not over-pickled. A good clean surface on a galvanized article which is not over-pickled should give a spangle as shown in Fig. 31. If it is desired to obtain a spangle upon an article which is made out of tinplate, this can



FIG. 32. SPANGLE ON ACID-TREATED TINPLATE
(*Natural Size*)

be done by dipping the tinplate into a very weak solution of nitric acid for a minute or two, when the crystalline structure of the tin on the surface of the tinplate will be developed as shown in Fig. 32.

WORKING SHEET METAL INTO ARTICLES

There is no limit to the articles of various designs, shapes, and sizes, into which sheet metal can be worked. A photograph of a few articles made by students of the Liverpool Technical College metal-working classes is shown in Fig. 33. These are variously made out of iron, copper, zinc, brass, etc., and give some notion of the kind of setting out for development work which is required for the respective articles.

MACHINES FOR RAPID PRODUCTION OF SHEET METAL WORK

For rapid production of repetition sheet metal parts, it is universal practice to use press tools on power presses. As already stated on page 45, the success of the work depends on the tools, but where these have been properly designed and made by skilled press tool makers, a large number of parts can be produced with precision and rapidity. A modern motorized power press is shown in Fig. 34. It is powerfully geared and driven with a 3 h.p. electric motor, and has a stroke of 3 in. There is a clutch on the cranked driving shaft which is controlled by the operator with the foot tread shown at the right-hand side of Fig. 34.

In the case of heavy cylindrical tank work, it is usual to use a hydraulic press for dishing or flanging the ends of the tank, the body of the tank being formed by passing the metal plate through bending rolls, the joints being riveted or welded.

When making light metal drums and containers, having ends similar to those shown in the examples on page 40, it is now customary to use the swaging and jennying machine shown in Fig. 35. With this machine it is possible to do high-class work very quickly.

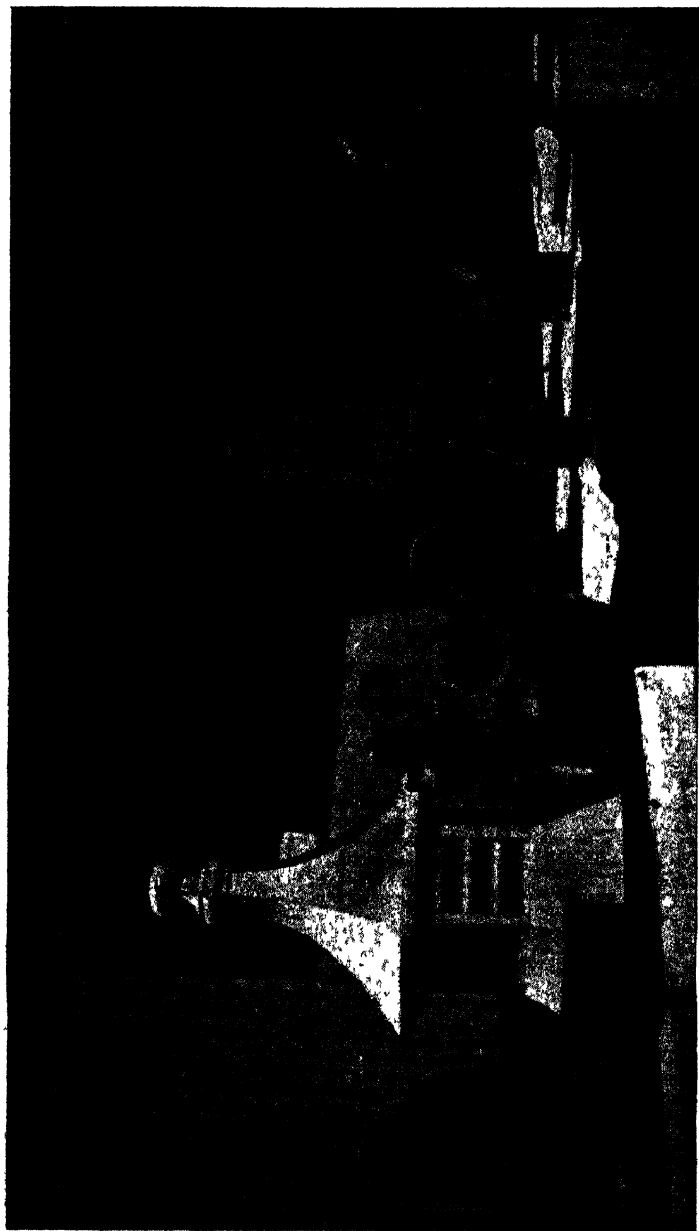


FIG. 33. SOME SPECIMENS OF WORK MADE BY STUDENTS OF THE LIVERPOOL
TECHNICAL COLLEGE

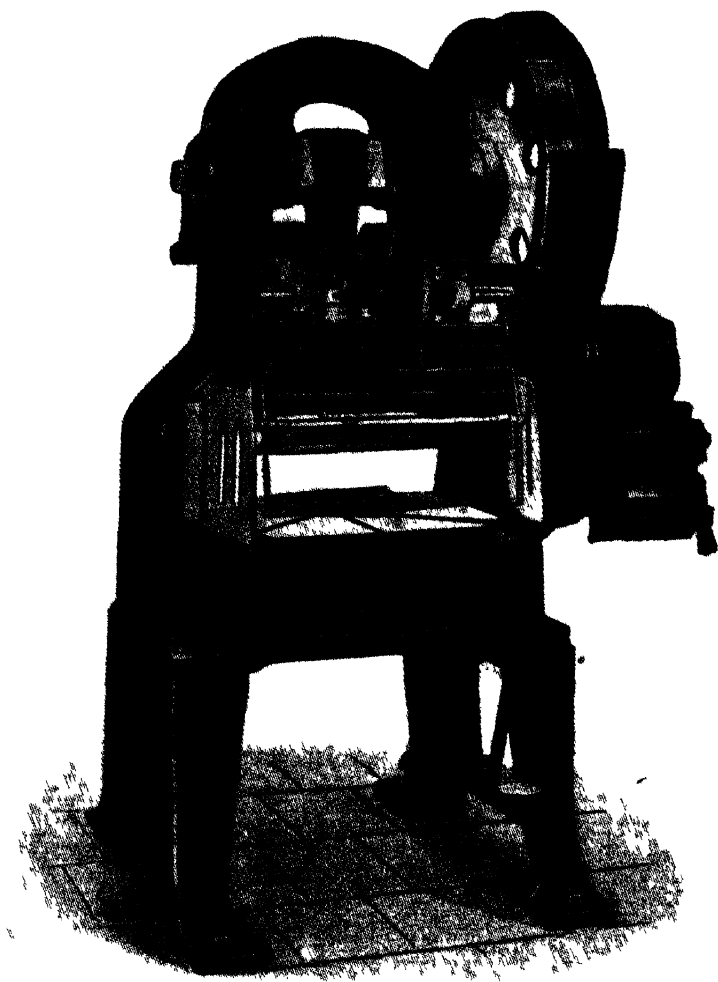


FIG. 34. EDWARDS 75-TON MOTORIZED POWER PRESS

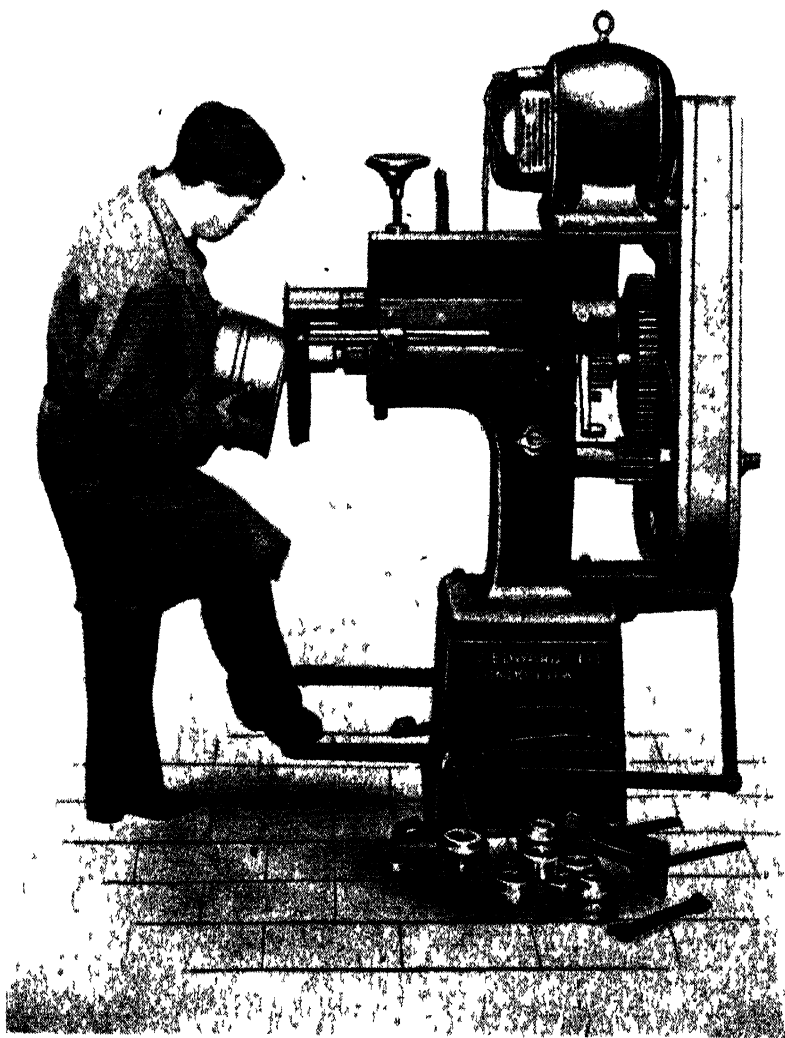


FIG. 35. EDWARDS MOTORIZED SWAGING AND JENNYING MACHINE

CYLINDRICAL PIPE ELBOW PATTERN

Fig. 36 demonstrates the elevation of a cylindrical pipe elbow and the development of one of its parts. For pipe work, generally speaking, the first important thing is to set out accurately either a complete or part

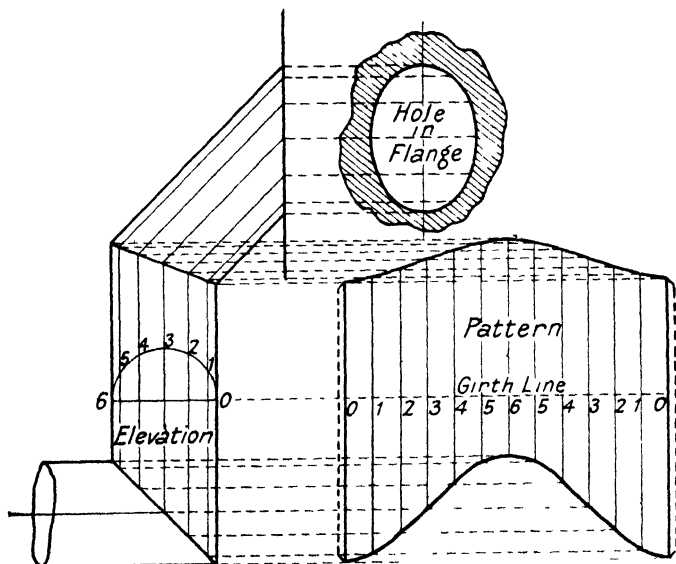


FIG. 36. SETTING OUT A PATTERN FOR CYLINDRICAL PIPE BEND

elevation, so as to show the joints in the correct position. Usually, the best way to do this is to draw in the centre line or lines of the pipe elbow, and then to clothe this or these with the outline of the pipe, thus obtaining the respective joint line.

In Fig. 36 it will be observed that three pieces of pipe are connected together to form the elbow, and that the top pipe is cut vertically with a flange fitted on the end. The pattern is set out by first of all describing

a semicircle, as shown, on some part of the pipe ; this is then divided into six equal parts, and lines through each division point run along parallel to the centre lines of the elbow. The girth line of the pattern is laid out by marking twelve lengths along, each being equal to one of the divisions on the semicircle, these reading from the centre in both directions from 6 to 0. Vertical lines are run up through each of the division points on the girth line, these being cut off to the length of the corresponding line shown on the elevation. The points so obtained are jointed up with a curve which, of course, forms the cut for the pipe joint.

In actual practice, instead of projecting the lines out as shown, the lengths are measured off the elevation and set along the pattern construction lines. The horizontal dotted lines are put in to show from where the respective lengths have been obtained.

In practical work it should always be remembered that the minimum number of lines actually required for the correct marking out of the pattern should be employed. The patterns for the top and bottom flange pipes of the elbow can be set out in the same way as the one shown, but it should be noticed that the cut on the bottom of the top pipe is the same as that at the upper end of the middle pipe, and also that the cut on the end of the horizontal pipe will be the same as that at the bottom of the pattern set out. The hole for the flange is also shown marked out, this, of course, being an ellipse. The shape of this ellipse can readily be obtained by setting its centre line out as shown with the respective distance as marked. The widths of the ellipse each side of the centre line, it will be seen, correspond to the lines shown marked on the semicircle.

On the pattern marked out the allowance for seam is indicated by the dotted lines. The allowance put

on the ends should be suitable for the particular method of jointing adopted.

PATTERNS FOR CONICAL ARTICLES

A pattern for any form of conical article can be made by taking the slant height of the cone or cap as a radius in marking out the centre of a circle, making the length of the arc equal to the circumference of a cone, and joining the ends up to the centre from which the arc has been described.

In putting allowances on the pattern for seams these should always be parallel to the end line of the net pattern, so that when the sheet is worked up the two end lines will come exactly together. If care is not taken to joint conical articles up in this way they will become slightly lopsided when brought into shape.

Conical or circular-tapered pipes can be jointed accurately to cylindrical pipes if, in the first instance, the correct position of joint line between the two pipes is obtained on the elevation. An illustration of this class of work is shown in Fig. 37. To get the exact position of the joint line the two pipes should be so arranged that, in elevation, they lie respectively tangential to an inscribed circle. Geometrically, it means that the cone and cylinder lie tangential to an inscribed sphere which is the same diameter as the cylinder. So long as this condition obtains, the cut across the cone and the cut across the cylinder will give two ellipses that are identical in size and shape.

After the joint line has been obtained, as shown in the elevation of Fig. 37, the setting out of the pattern for the conical pipe becomes simple. A semicircle is drawn on the base of the cone, divided into six equal parts, and from each numbered division point lines are drawn square to the base of the cone, then joined up to the apex *A*. Where these respective radial lines pass

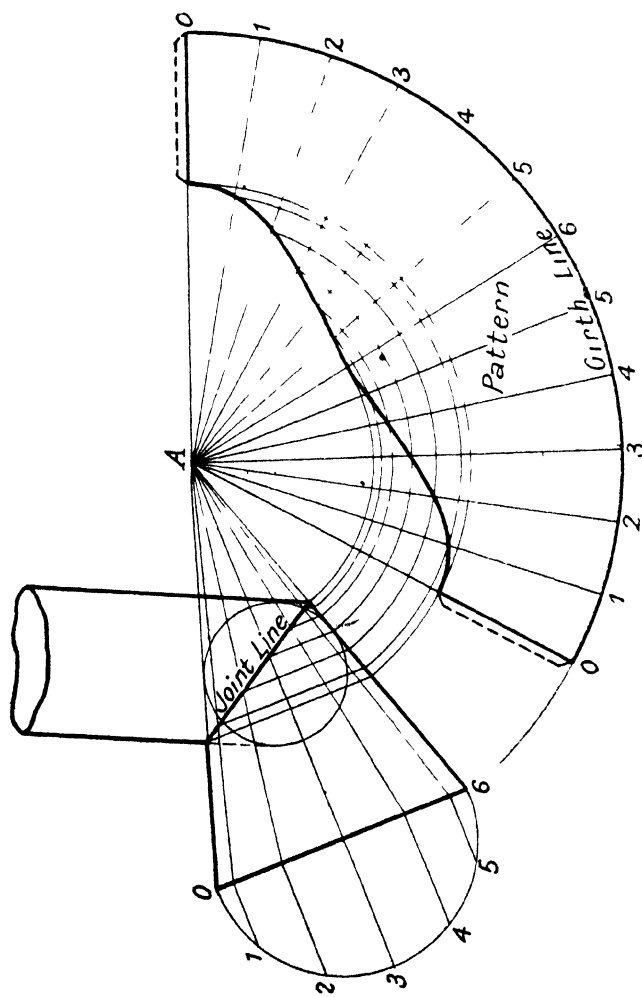


FIG. 37. SETTING OUT A PATTERN FOR CONICAL PIPE BEND

through the joint, lines are run out at right angles to the centre line of the cone until they meet the slant side. After drawing the pattern for the complete cone and the radial lines on it, the correct position of the points to obtain the pattern cut are measured from *A*, down the slant side *AB*, and marked on to the corresponding numbered lines of the pattern. The pattern for the cylindrical pipe can be set out as indicated in Fig. 36.

It might be mentioned that patterns for two or three-way pieces for conical and cylindrical pipes, or conical pipes alone, can be set out by first of all obtaining the exact position of the joint lines by the method used in connection with Fig. 37.

PATTERNS FOR MOULDING OR CORNICES

The cutting out of sheet metal patterns to form angles or elbows for gutters or cornices can be very easily done by the method shown in Fig. 38. The section is given of a sheet metal moulding, and this is marked off into the respective divisions as numbered. The girth line is marked down from 0 to 9, the respective parts of which have been taken from the corresponding lengths in the elevation. Through each of the division points lines are then run out at right angles to the girth line, these then being cut off equal in length to the lines of the corresponding numbers on the section. When the points are joined up as shown this will give the shape of the pattern, which, when bent to the required shape, will form the right-angle elbow. In bending the two arms to form the elbow, care should be taken to see they are bent respectively right and left hand, and to the exact shape and size. It might also be mentioned that unless the greatest care is taken to set the pattern out exactly, difficulty will be found in forming the mitre joint. As a guide in joining

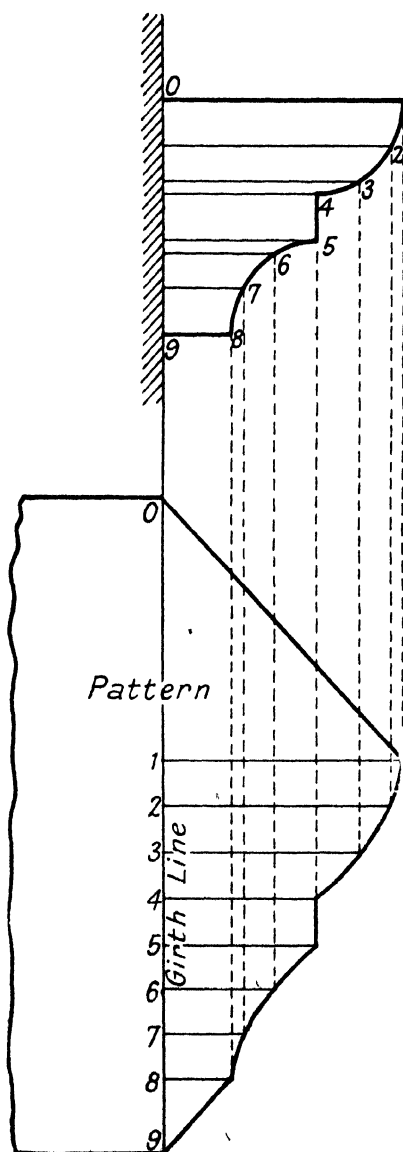


FIG. 38. SETTING OUT A PATTERN FOR ANGLE OR ELBOW OF CORNICE OR MOULDING

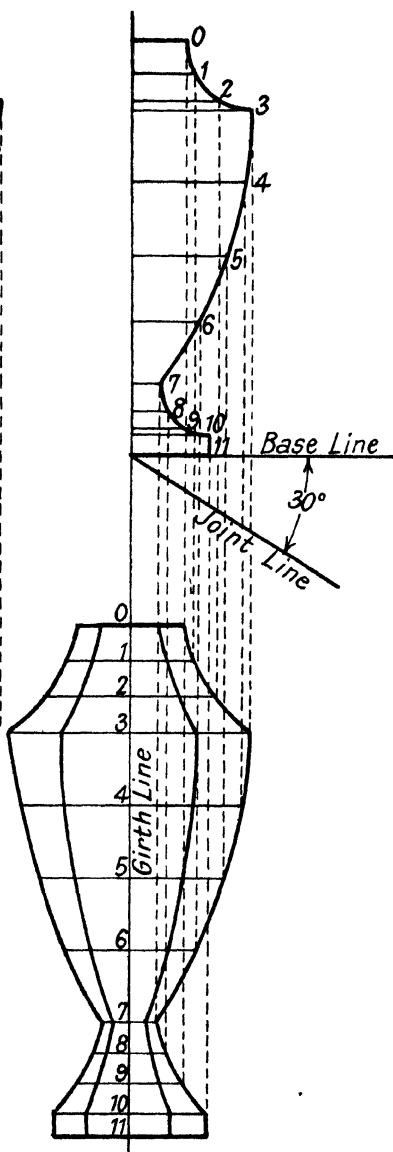


FIG. 39. SETTING OUT OF STRIP PATTERN FOR SQUARE AND OCTAGONAL VASES

up the respective points on the pattern, it will be noticed that straight lines on the pattern cut are those which correspond to straight lines on the elevation. Thus 0 to 1 is a straight line, consequently the cut on the pattern will also be a straight line. The same also applies to the points 4 and 5, and 8 and 9.

STRIP WORK FOR VASES, ETC.

This class of work is quite easy to make and is particularly suitable for the amateur, the only requisite being that it should be carried out with a great degree of accuracy.

In Fig. 39, the half-elevation is shown of a square vase, by which is meant that all horizontal sections of the vase will be square. The body of this article would, of course, be made up in four pieces, the pattern for one of the pieces being shown by outer lines of the lower figure in Fig. 39.

The girth line is first set out as with the previous example, lines then being run at right angles to this through each respectively numbered point, the lengths of these lines being cut off as shown by the dotted lines which are drawn from the half-elevation.

If it is required to make a vase of more than four pieces, then it is necessary to set the pattern out somewhat differently. Thus, the pattern for a strip for working up to form a hexagonal vase will be obtained by marking out a joint line at an angle of 30 degrees to the base line, and where the vertical dotted lines from the respective points in the section cross between base and joint line will give the required lengths for marking out the pattern. These lengths are then measured off and set each side of the girth line on the pattern; such a pattern is shown by the two inner curves on Fig. 39.

PATTERNS BY METHOD OF TRIANGULATION

In some cases it is either impossible or extremely difficult to set out a pattern by the ordinary methods of development applied to cones, cylinders, etc., and, in such cases, what is known as the "method of triangulation" is applied. Essentially, it means the surface which is required to be developed or laid out in the flat is divided up into triangles, and the respective lengths of each side of the triangles obtained and so set out, thus building up the pattern by adding together the whole of the triangles which make up the total surface of the article. This method is illustrated by Fig. 40. The article shown in elevation and half-plan is that of a funnel which is circular at the top and rectangular at the bottom. The pattern is obtained by measuring off the line $C6$ in the elevation and setting it down for the middle line of the pattern, then drawing CB at right angles to this and making it equal to the corresponding line in the half-plan. The point 5 on the pattern is found by getting the true length of the line $5B$ from the elevation, this being found by setting off the length 5^1B along the base line from the foot of the perpendicular drawn through 5^1 , and then measuring up to where the line drawn through 5 (on the semicircle) meets the line 06 . This length is then used as a radius from the point B on the pattern, and the arc so drawn cut by taking the length 65 equally to one of the arcs in the elevation. In the same way the length $B4$ on the pattern can be obtained by setting the length 4^1B from the foot of the perpendicular through 4^1 along the base line, and measuring up to the corresponding point on the line 06 . Similarly, all the other points of the pattern can be obtained.

This method of triangulation, it may be mentioned,

can be used for the setting out of patterns for any kind of article that it is possible to work up into sheet or

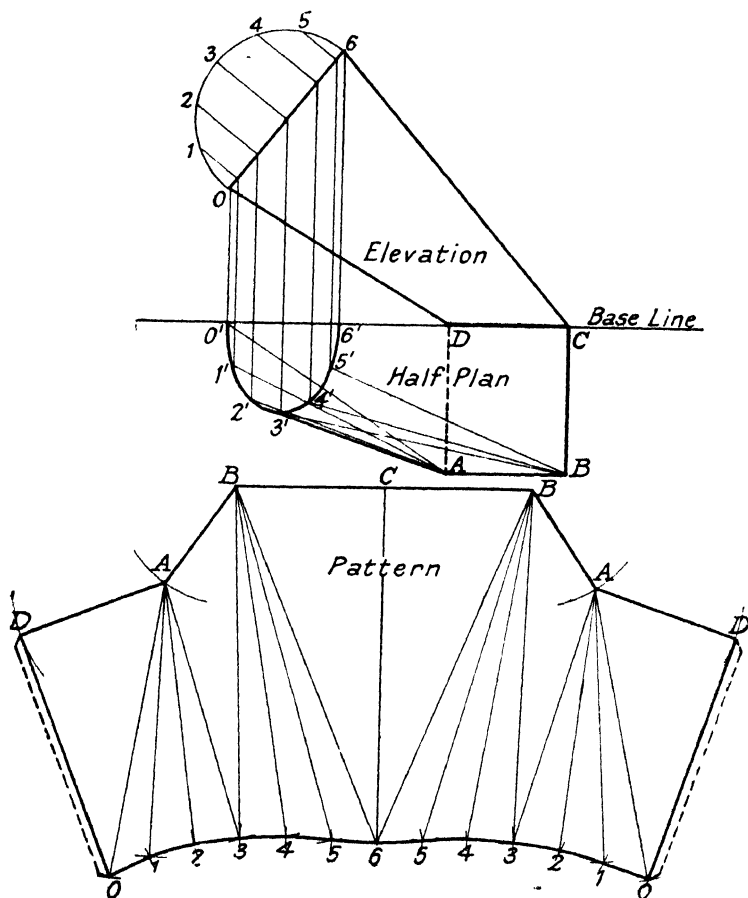


FIG. 40. SHOWING METHOD OF TRIANGULATION IN SETTING OUT PATTERN FOR AN IRREGULAR-SHAPED ARTICLE

plate metal. For twisted surfaces it also gives a pattern which is as near as it is possible to obtain for surfaces which, strictly speaking, cannot be developed,

and which when they are worked up into shape must be stretched at certain parts to bring them into their correct form.

THE CHOICE OF METALS

Although there are a great number of metals in Nature, there are comparatively few which for one reason or another lend themselves for use by the sheet- and plate-metal worker. Platinum, gold, and silver are excellent metals from the point of view of possessing suitable properties for working into various shapes, but manifestly on account of their scarcity and consequent high cost they can only be used for very special purposes. Similarly, there are many other metals which, on account of their rareness or unsuitable properties, are of little use to the metal worker. The metals which in industry are commonly used are iron, copper, zinc, aluminium, tin, and lead; and alloys of these, such as the various steels, brasses, bronzes, pewter, and so-called rustless irons and steels, which are usually alloys of iron, nickel, and chromium.

In choosing a metal to be used in any particular kind of work, consideration must be given in the first place to the use to which the article is to be put and the cost of the metal. Where considerations of strength alone arise, steel in one or other of its forms is used. Where it is required to transfer heat rapidly through the metal for the evaporation of water or other liquid, such as in the firebox of a locomotive boiler or chemical vessels, the metal copper is used. Or, in the case of smaller vessels, aluminium is used if there is not likely to be any objectionable chemical reaction on the inner surface of the vessel.

For domestic purposes tin-lined copper and iron pans are used, the tin coating resisting the action of vegetable and meat juices which would otherwise

attack either copper or iron. For similar purposes also, vessels made of aluminium are used.

For outdoor purposes, where cost is not the first consideration, sheet copper is occasionally used for covering. For cheaper work sheet lead is used, or zinc; but the commonest kind of sheet covering is that of galvanized sheet iron, which is mild steel coated with zinc.

PROPERTIES OF METALS

Some metals are used on account of their strength, and in this connection it should be noted that the strength of pure iron is about 19 tons per sq. in., mild steel about 24 tons per sq. in., and boiler plate about 30 tons per sq. in., but the strength of these materials depends upon whether they are in the hard rolled condition or annealed. The strength of a mild steel sheet, which in the annealed state might be 20 tons per sq. in., can be raised to almost 40 tons per sq. in. if it is hard rolled. Copper comes next in strength to iron, this having a tensile strength of about 15 tons per sq. in. in the annealed state, running up to 30 tons per sq. in. or more in the hard rolled condition. Soft aluminium has a tensile strength of about 5–6 tons per sq. in., but this again like the other metals can be considerably strengthened by having cold work done upon it. Zinc, tin, and lead are not usually used where great strength is required.

Where sheets or plates have to be hollowed, the toughest metals for this purpose are copper and aluminium. Zinc, however, in its very purest form is quite a malleable metal. Lead and block tin can quite conveniently be worked into various shapes, but care must be taken not to put too severe a strain on these metals on account of their little strength.

Sheet and plate iron of the open-hearth kind, when

in a pure form and properly annealed, can be well shaped into a variety of forms. In the lists given it will be seen that copper is an extremely good conductor of heat, aluminium coming next in order. For these reasons, the metals mentioned can be used where it is necessary to have a rapid transfer of heat through the plate. For reference purposes use should be made of the following table—

Conducting power for heat	Melting point (Cent.)	Specific gravity	Linear expansion for 1° C.	Specific heat	Weight per cub. ft. in lb.
Copper .	1083	8.95	.000017	.0951	550
Aluminium .	658	2.67	.000023	.2143	166
Zinc .	419	7.14	.000029	.0955	440
Tin .	232	7.29	.000025	.0562	455
Iron .	1530	7.84	.000013	.1138	480
Lead .	327	11.36	.000028	.0314	710

The amount which metals expand under a given rise of temperature varies very considerably with the metal. Thus, on examining the table it will be seen that lead expands as compared to iron in the ratio of 28 to 13, or, in other words, under any given rise of temperature lead will expand more than twice the length of iron. It will also be seen that zinc expands slightly more than lead, this high expansion in these two metals being the reason why sheets of zinc and lead buckle when fixed firmly for roofing purposes.

The figures under the heading of specific heat might be explained by showing that they represent the quantity of heat the respective metals would take up through any rise of temperature, when compared to the same weight of water. Thus, it will be noticed that aluminium will absorb about one-fifth the amount of heat that an equal weight of water would when heated through the same range of temperature. The figures show that there is a very great variation in this property

in the metals given. If the same weights of lead and zinc are both heated up to equal temperatures it will require just three times as much heat to raise the temperature of the zinc as that of the lead. Conversely, it should be remembered that when the metals cool down again lead will give out only one-third as much heat as the zinc.

From the specific gravity and weight per cubic foot columns it will be observed that the weights of metals vary considerably ; thus the heaviest metal is lead and the lightest aluminium, the latter metal volume for volume being about a quarter the weight of lead. These relative weights as they are called are sometimes useful in enabling one to tell whether one metal will float or sink in the other when in the molten condition. Thus, if a bar of iron be put into a bath of molten lead it will float, whilst if it is placed in a bath of molten zinc or tin it will sink.

Iron melts at the highest temperature of all the industrial metals, in its purest form melting at about 1550°C . The more impure it is, or when in the form of steel, the lower is its melting point. Pure copper melts at 1083°C ., this temperature again being reduced when any impurities are present.

When metals are mixed together to form alloys their melting point is lowered, in some cases below that of both the metals, and in others below that of one of them. A good illustration of this is ordinary solder which is composed of equal parts of lead and tin. This has a melting point of 150°C ., which it will be noticed is 82°C . below that of tin and 177°C . below that of lead. Similarly, in the brasses which are composed of copper and zinc, it will be found that the melting point is usually 200° or 300°C . below that of copper.

SECTION XXV

SURFACE TREATMENT OF METALS

BY

E. A. ATKINS, M.I.MECH.E., M.I.W.E.

SECTION XXV

SURFACE TREATMENT OF METALS

INTRODUCTION

THE ordinary metals and alloys which are used for industrial, domestic, or other purposes, so readily corrode or tarnish when exposed to the atmosphere, that it is necessary to treat the surface in some way that will enable the metal to resist corrosion or tarnishing for the longest possible period.

In addition to the surface of metals being treated to resist corrosion, they are sometimes coated, lacquered, or otherwise dealt with to give a particular colour or appearance suitable for certain conditions. Unfortunately, the cheapest metals such as cast iron, wrought iron, and mild steel, whilst possessing many important properties such as hardness, strength, ductility, etc., have one very distinct disadvantage in that they rapidly waste away when subjected to an atmosphere of a corroding character if their surfaces do not receive adequate protection, and this is particularly so with mild steel.

The cause of the continued corrosion of iron and steel is due to the fact that the products formed on the surface of the metals are not only easily removed by falling or dissolving away, but actually accelerate the wasting of the remaining base metal. The worst of the metals in this respect are iron and steel. Whilst other metals such as copper, zinc, tin, and lead very quickly tarnish or corrode when exposed to the atmosphere, the resulting surface product of corrosion

firmly adheres to the base metal and is not easily removed or dissolved away ; in this manner the film of oxide or carbonate acts more or less as a protecting skin to inhibit further attack.

There are a great many ways in which the surfaces of metals are treated, such as hot and cold galvanizing, tinning and lead coating, sherardizing, spraying of hot metal, electro-plating by either cadmium, chromium, nickel or other metals, vitreous or porcelain enamelling, black enamelling or japanning, caloricizing or cosletizing, lacquering, varnishing, oiling, painting, etc. There is also the method of armouring which is not very commonly in use, this consisting of welding a layer of metal such as copper on to the surface of steel, which is then rolled into plate or drawn into wire ; but as this method of protecting a base metal is so expensive it has come very little into use.

If iron or steel is effectively coated with a thick non-porous layer of either copper, zinc, tin or lead, there is no doubt but that it can be effectively protected from atmospheric corrosion ; but, unfortunately, with the three metals, copper, tin and lead, it is extremely difficult with the ordinary methods of coating to put an absolutely non-porous coat on an iron or steel base metal, the result being that corrosion first takes place at the microscopic holes in the coat, then continues under the coating metal, pushing this completely away. The cause of this is due to the fact that the three metals mentioned are all electro-negative to iron, and, consequently, with a porous coating rapidly accelerate the corroding of the base metal.

A good illustration of this is in the case of the corrosion of tinplate when exposed to the atmosphere. It appears somewhat strange that block tin or tin in the ingot form is practically immune from corrosion when exposed to the air. Yet, when the same metal is

applied to the surface of an iron or steel sheet, corrosion commences to take place in a few hours in a damp atmosphere. This is caused, as already mentioned, by the microscopic pin holes setting up corrosion in the first instance, then this creeping under the coating of tin, ultimately removing the latter.

When a thin coating of copper is applied to iron or steel by simple immersion in a copper-sulphate solution the corrosion which follows is so rapid that, under the microscope, it can be seen to "grow." This rapid growth of corrosion is, as already mentioned, due to the formation of electrolytic action. However, in practice it usually happens that the thicker the coat the less is its porosity, consequently the less rapid is the corrosion.

It is somewhat different in the case of a zinc coating, as this metal being electro-positive to iron or steel assists to protect the underlying metal where the surface is porous, or the coating metal cracked or otherwise damaged.

The most commonly applied coating for the protection of the surface of iron or steel against atmospheric corrosion is that of galvanizing, and of the various methods which are in vogue the hot or dip method is the one which is the most commonly used.

METHODS OF ZINC COATING

Four methods of applying zinc to iron or steel are now in use, these being as follows—

1. Hot dip (galvanizing) process.
2. Electrolytic- or zinc-plating.
3. Sherardizing.
4. Spraying of hot metal.

Like many other useful processes, the origin of hot galvanizing is very obscure. The earliest accounts indicate that the idea of using zinc for coating other

metals arose as soon as zinc was known in Europe during the first half of the eighteenth century, and that iron cooking utensils were being hot galvanized at Rouen in France as early as 1778.

In *Chemical Essays*, published in 1786, Bishop Richard Watson wrote the following—

“ A method has of late years (1778) been introduced at Rouen of applying a coating of zinc upon hammered iron saucepans. The vessels are first made very bright, so that not a black speck can be seen ; they are then rubbed with a solution of sal-ammoniac, and afterwards dipped into an iron pot full of melted zinc ; on being taken out, the zinc is found to cover the surface of the iron, and if a thicker coat of zinc is wanted, it may be obtained by dipping the vessel a second time. This kind of covering is so hard that the vessels may be scoured with sand without its being rubbed off.”

On account of the simplicity of the process there is no doubt that the coating of iron with zinc had been performed in early times by a good many experimenters, but the first patent for hot dip galvanizing was taken out by Crawford in England in 1837.

Why the term “galvanized” was chosen it is somewhat difficult to understand, as no particular galvanic action takes place in the process, other than that which is common, possibly, to all forms of chemical reaction.

There is, however, a galvanic or electrolytic action brought into operation when the coated iron is exposed to the atmosphere, on account of zinc being electro-positive to iron, this action resulting in the protection of the iron.

The process was originally applied to small articles of iron, then to hollow ware, such as buckets, bowls, etc., and later applied to the much more extended field of sheet iron and wire.

The discoverer probably never dreamt of the wide

application to which his process would be applied, and, although it is over a century since it was first commonly used, there is nothing up to the present which to any degree is able to supplant this method of protecting iron from the corroding influence of the atmosphere.

THE HOT DIPPING PROCESS

As the hot dip process is the most widely used, and the one which undoubtedly gives the best coating for outside exposure, it is worth while considering the process in some detail.

Essentially the dipping process consists in having a wrought iron or mild steel bath (Fig. 1) containing spelter*, which is kept in a molten condition by some form of firing ; either with a coke fire around the outer surface, or coal, oil or gas fire with the necessary flues passing around the pot.

Whilst for simple dipping purposes an open bath is used of a size suitable for the work to be galvanized, yet for sheets, wire, netting, plates, tubes, etc., special forms of baths and machinery are required. The temperature of the bath may be from $430^{\circ}/480^{\circ}$ C., depending upon the kind of article being galvanized and the kind of coat required. The article to be dipped is first thoroughly cleaned in hydrochloric acid, then dried, warmed, and carefully dipped into the molten zinc after the surface of the latter has been sprinkled with sal-ammoniac, or muriate of ammonia as it is commercially called. After the surplus spelter is drained or shaken from the article it is usual to plunge it quickly in and out of water, so as to wash away any spent muriate of ammonia that may remain on the surface. The article must not be completely cooled out in the water except under exceptional circumstances with small articles such as nails, washers, rivets, etc.,

* Spelter is the commercial name for zinc.

as it is necessary to have the article completely dry before it is exposed to the atmosphere. In dealing with small things such as those mentioned, it is usual to dry them by rubbing in hot sawdust.

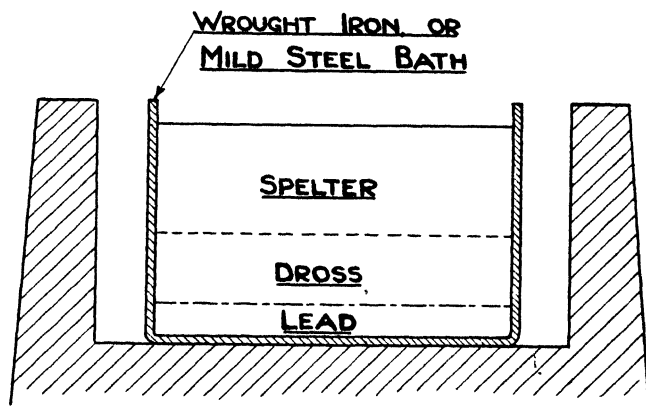


FIG. 1. SECTION OF GALVANIZING BATH

“SECRETS” IN CONNECTION WITH GALVANIZING

In the early days the so-called “mysteries” connected with the carrying out of the process were very jealously guarded, and, indeed, in some galvanizing works it was thought that an article could not be properly coated except by the use of some mystic pill or compound which a potman occasionally drew from his waistcoat pocket and supplied to the pot in homœopathic doses. In more modern days this kind of wizardry has disappeared, and the method of galvanizing has been reduced to a plain, straightforward operation.

When galvanizing was first introduced there was considerable fear that the products which came away in the atmosphere from the galvanizing process were

extremely dangerous, and, consequently, early galvanizing pots were placed at the bottom of tall chimney stacks, the stack itself being supported on four heavy brick columns at the corners with archways in between. Whilst coke and zinc fumes were certainly carried up the chimney stack, the draught about the pot was at times sufficiently strong almost to remove the potman's coat from his back. It was, of course, subsequently found that more convenient methods of ventilation could be used.

Whilst the art of galvanizing has been stripped of its early mysteries, it should not be forgotten that there are a number of important factors which regulate the quality of galvanizing, and although these are not common property, they are known by those who are more intimately connected with the technical side of the process.

THEORY OF HOT GALVANIZING

The whole basis of the coating of iron or steel with zinc by the hot method depends upon the extraordinary property which molten zinc has of dissolving solid iron. This, of course, can be proved in a great number of ways. Thus, if a piece of wire rod or bar is left suspended in a galvanizing pot sufficiently long it will in time be found to have been completely dissolved away. This is very peculiar when it is remembered that there is an enormous difference between the melting point of zinc and the melting point of iron, these being respectively about 419°C. and 1500°C. But the action is not one of simply melting, for the molten zinc dissolves the iron and combines with it to form a zinc-iron compound, this usually having a composition of about 89 per cent zinc and 11 per cent iron.

What actually takes place when a bar of iron has been left to dissolve in a galvanizing bath is clearly

indicated in Fig. 2. This shows a little of the cross-section of a piece of rod (magnified 100 diameters) which had been left lying in a galvanizing bath for a considerable time. It will be seen that the compound adjoining the bar is formed of the solid zinc-iron alloy,



(Magnification 100 diameters)

FIG. 2. PHOTOMICROGRAPH OF A SECTION
OF STEEL ROD

Showing iron-zinc alloy on surface and radiating crystals

whilst radiating from it upwards are crystals (white) of this same alloy "floating" in zinc (black).

The photomicrograph clearly shows the "growth" of the zinc-iron crystals, using the iron of the bar as the material required to join with the necessary zinc to form the alloy.

FORMATION OF DROSS IN BATH

In connection with the working of the process, whether it be for small articles, sheets, wire, hoops,

etc., a peculiar by-product is formed in the molten metal which is called "dross" or "hard spelter." An analysis of this is given in the table of spelters. This dross is really an alloy of zinc and iron, being composed of about 96 per cent zinc and 4 per cent iron. A



(Magnification 100 diameters)

FIG. 3. PHOTOMICROGRAPH OF DROSS, CONTAINING 4 PER CENT IRON FROM GALVANIZING POT

photomicrograph illustrating the structure of the dross is shown in Fig. 3, in which the crystals of the zinc-iron alloy (white) are seen floating in a matrix of zinc.

The dross gathers in the pot as shown in Fig. 1, and lies between the spelter at the top portion of the bath and the layer of lead which collects at the bottom.

The dross in the pot is formed from three sources—

1. The molten zinc dissolving a small quantity of iron from the surface of the article being galvanized.

2. The dissolving of the inner surface of the galvanizing bath by the molten zinc.

3. The breaking up of any iron chloride which may be carried into the bath to form zinc chloride on the one hand, and crystalites of zinc-iron on the other.

The amount of iron dissolved from the article being galvanized will be roughly proportional to the temperature of the molten zinc and the time of immersion. At temperatures above 470°C . the solvent action increases very rapidly, and at about 520°C . the solvent power of the zinc for iron is about twenty times greater than at the lower temperature.

The rate at which the inner surface of the galvanizing bath will be dissolved depends upon the quality and homogeneity of the iron or steel bath and the temperature to which the bath and the zinc in contact are raised, local heating being the chief source of pitting on the inside of the bath.

After iron articles have been pickled in hydrochloric acid they carry on their surface a solution of iron chloride, this being one of the most fruitful sources in the formation of the zinc-iron crystals.

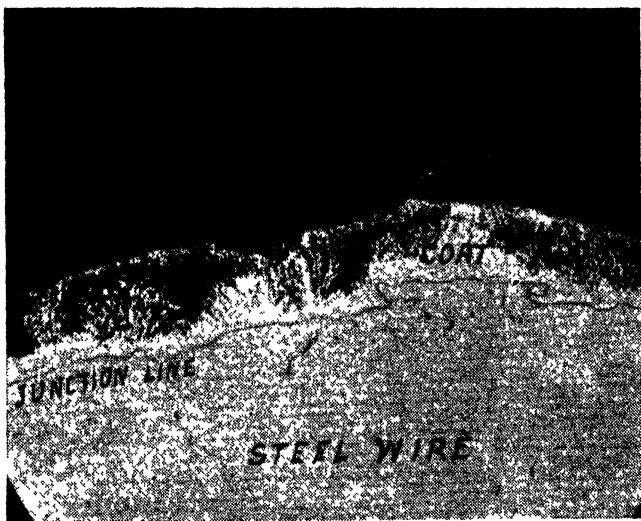
For economical galvanizing it is essential that the iron chloride should be removed from the surface of the article before it is dipped in the molten zinc. Generally, the reason why it is left on is that in itself it forms a flux by the changing of the iron chloride into zinc chloride, but, as articles can be covered with a thin solution of zinc chloride (or ammonium chloride) after being washed, there is no excuse for continuing such a wasteful process as often obtains.

The small crystals of the zinc-iron alloy formed from the above three sources gather together to form large crystals, which having a greater density than the molten spelter gradually sink downwards to make the bed of dross as shown in Fig. 1. It is necessary at regular

periods to remove the dross, which being in a pasty condition is easily done by the use of a perforated scoop. The dross is then subsequently treated, the zinc being recovered.

THE GALVANIZING OF WIRE

It is not an easy matter to make a section of either a galvanized sheet or wire so as to show clearly the



(Magnification 100 diameters)

FIG. 4. PHOTOMICROGRAPH OF A PART SECTION OF HOT GALVANIZED STEEL WIRE

coating and the junction of the coat and the steel base, but by a special method the photomicrograph shown in Fig. 4 has been prepared, this showing not only the steel wire but the junction of the wire and the zinc-iron alloy, also the purer spelter near the surface.

Careful examination of the photomicrograph shows the fine crystals of the zinc-iron alloy just above the

junction line, stretching out in tree-like form to the purer zinc near the surface of the wire.

Wire for telegraph lines and other purposes is galvanized by a continuous process in which the wires running parallel are passed through an annealing furnace, then an acid cleaning cistern, a washing tank, a

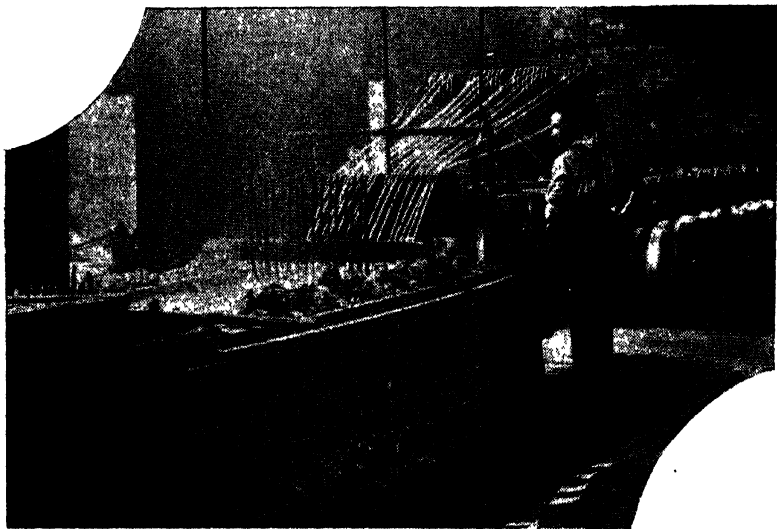


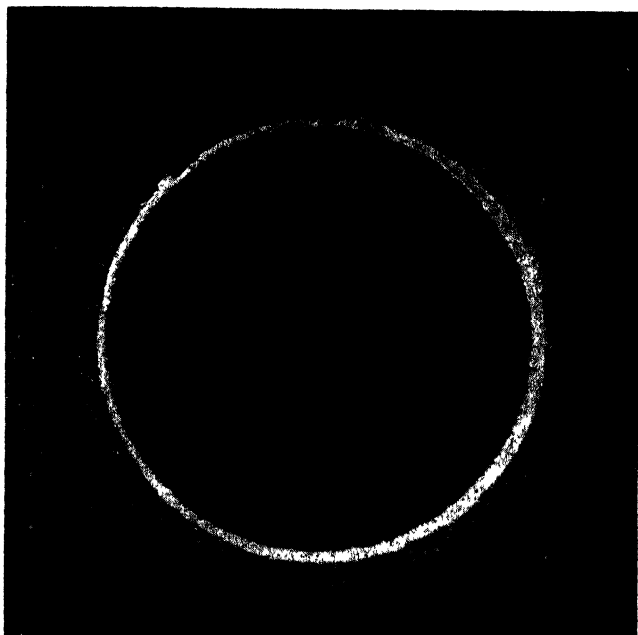
FIG. 5. A WIRE GALVANIZING BATH

fluxing cistern, over a drying plate, and on through the molten zinc of the galvanizing bath, and finally to the winding blocks. To regulate the thickness of the coat on the wires, it is usual to have a bed of moist sand on the surface of the out-going end of the bath through which the coated wires pass. A photograph of such a plant is shown in Fig. 5.

Where wire is required to have a thin flexible coat it is usual to pass it through close asbestos wipers, or an equivalent, instead of drawing it through a sand bed.

There are several special methods of galvanizing in

operation with a view to producing an even flexible coat, and one which will stand up for the maximum time under atmospheric corrosive conditions. An enlarged cross-section of an evenly galvanized wire is



(Magnification 25 diameters)

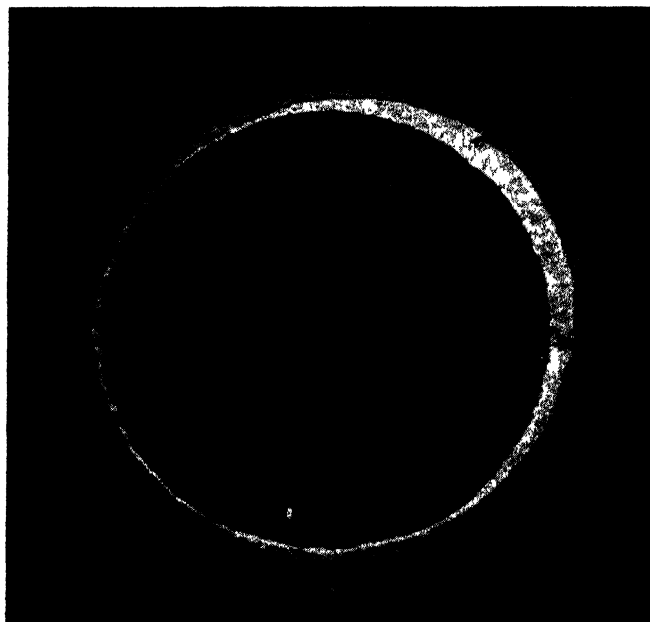
FIG. 6. SECTION OF EVENLY COATED
GALVANIZED WIRE

shown in Fig. 6, and an enlarged cross-section of a wire with an uneven coat is shown in Fig. 7. It is manifest that the wire which carries the most even coat of the highest quality is one which will give the best service when put into use.

THE MAKING OF GALVANIZED SHEETS

The manufacture of galvanized mild steel sheets is one of the most important metal industries in the

country, and in spite of competition from all quarters the United Kingdom has for many years up to the present time been able to hold the premier position in this trade, the total production being not less than



(Magnification 25 diameters)

FIG. 7. SECTION OF UNEVENLY COATED GALVANIZED WIRE

850,000 tons per year. From the old days, when a sheet of iron was galvanized by actually throwing it into a bath of molten zinc, letting it remain for a short time and then pulling it out, very great strides have been made.

Usually sheets are pickled in batches, either in hydrochloric acid or sulphuric acid, and after the scale has been completely removed they are washed in running water.

For the actual galvanizing, a plant is used of the character shown in Fig. 8. The clean wet sheet is passed through a flux box containing muriate of ammonia and so on through the molten metal, leaving the surface of the bath by a pair of horizontal rollers which serve the purpose of regulating the quantity of zinc that the sheets take up, and also keeping the oxide from passing out on the sheet surface.

The amount of spelter taken up on the surface of a sheet may vary from $1\frac{1}{4}$ to $2\frac{1}{4}$ oz. per square foot,

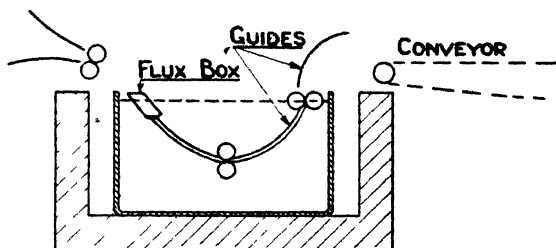


FIG. 8. SHEET GALVANIZING BATH

depending upon the kind of process used and the conditions of the process.

GALVANIZING SPANGLES

In the galvanizing of sheets, efforts are usually made to produce them with the largest and best formed spangles, as this type of sheet possesses good selling properties. A photograph of part of a spangled sheet is shown in Fig. 9, the fern-like structure of the spangles being of a very beautiful character.

It is somewhat peculiar that the quality of sheets is very often judged by the size and beauty of spangle, and this is especially so in Eastern markets. If the large spangle had any particular virtue other than that which appertains to its appearance something could be said for it, but, in any case, the beauty of the

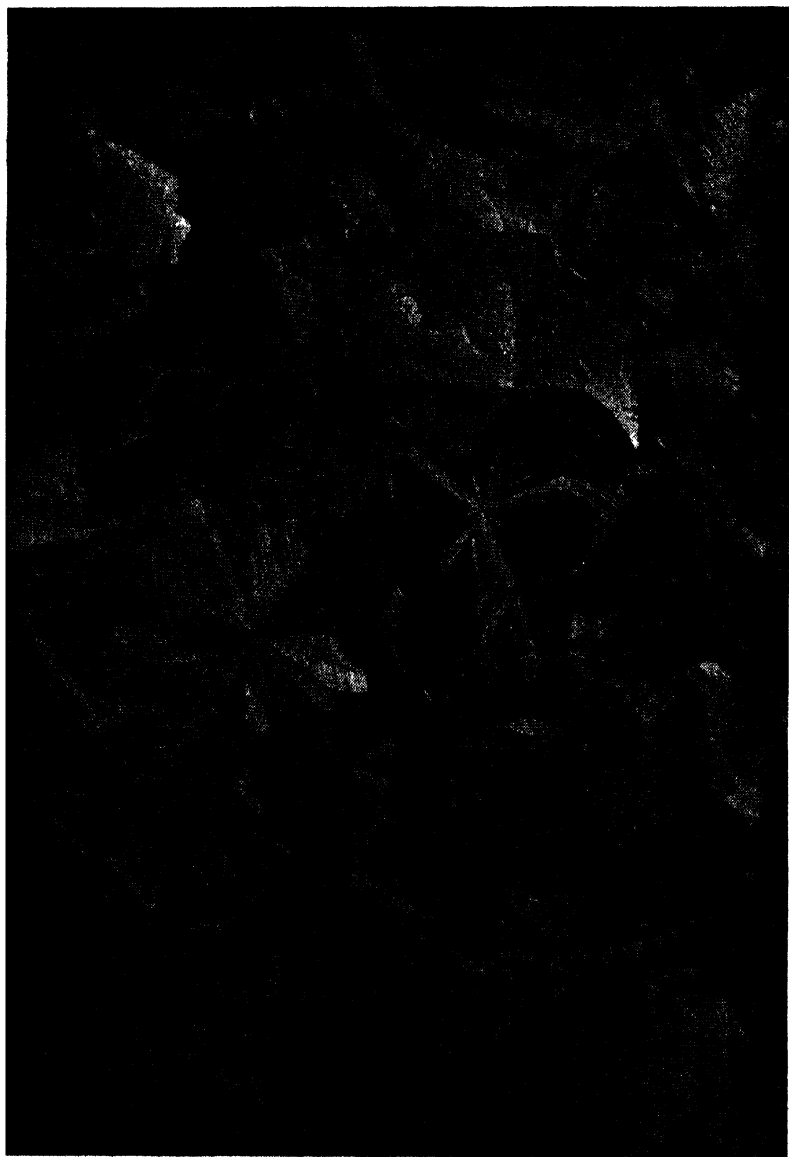
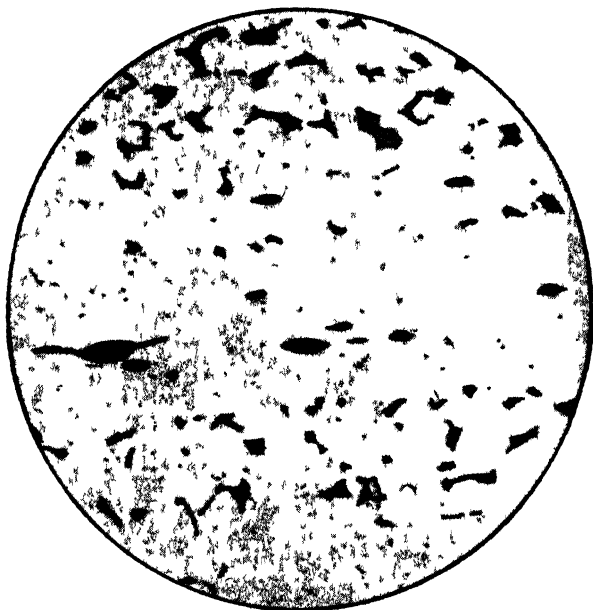


FIG. 9. FULL SIZE PHOTOGRAPH OF SPANGLES
ON GALVANIZED SHEET

spangle on sheets is, unfortunately, only ephemeral, as exposure to the atmosphere very soon dulls the appearance.

There is a difference of opinion as to what causes large and small spangles, but without entering very



(Magnification 100 diameters)

FIG 10. PHOTOMICROGRAPH SHOWING IRREGULAR
GRAINS AND MANGANESE SULPHIDE GLOBULE
INCLUSIONS IN STEEL SHEET

deeply into the scientific explanation, it may be said that the spangling is controlled by anything which alters the surface tension of the zinc. It can be proved that not only is the size of spangle affected, but also the general quality of the galvanized coat, by the following factors—

1. The quality of the steel.

2. The time and temperature of annealing.
3. The condition of the sheet surface, both before and after pickling.
4. The quality of the spelter.
5. The temperature of the galvanizing bath and time of immersion.
6. The method of galvanizing.



(Magnification 100 diameters)

FIG. 11. PHOTOMICROGRAPH SHOWING BANDED PHOSPHIDE INCLUSIONS IN STEEL SHEET

THE QUALITY OF STEEL

For the highest quality of galvanized sheets or wire, it is essential that the steel should be fairly clean and free from segregations and other defects. In Fig. 10 a photomicrograph is shown of a dirty steel exhibiting

large globules of manganese sulphide, whereas in Fig. 11 a steel high in phosphorus is shown, this kind of steel not only giving a very indifferent surface, but being of poor working-up quality.

Steels that show a great number of inclusions are always badly affected in pickling, absorbing a large volume of hydrogen which is given out in passing through the molten zinc of the galvanizing bath, as

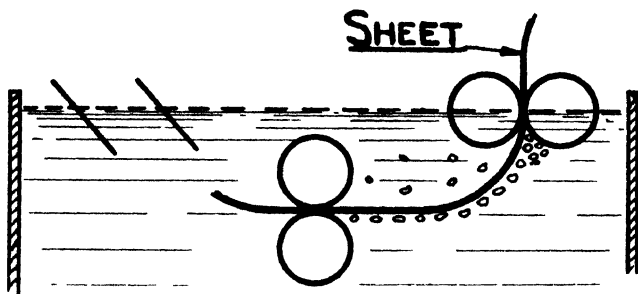


FIG. 12. BUBBLES OF HYDROGEN TRAPPED UNDER SHEET AND BEING CARRIED INTO SURFACE ROLLERS

shown in Fig. 12. These, becoming trapped in the surface rolls, cause the formation of a very thin coat on parts of the sheet.

Steels containing a large number of non-metallic inclusions invariably also result in the sheets rolled from them producing small spangles in galvanizing.

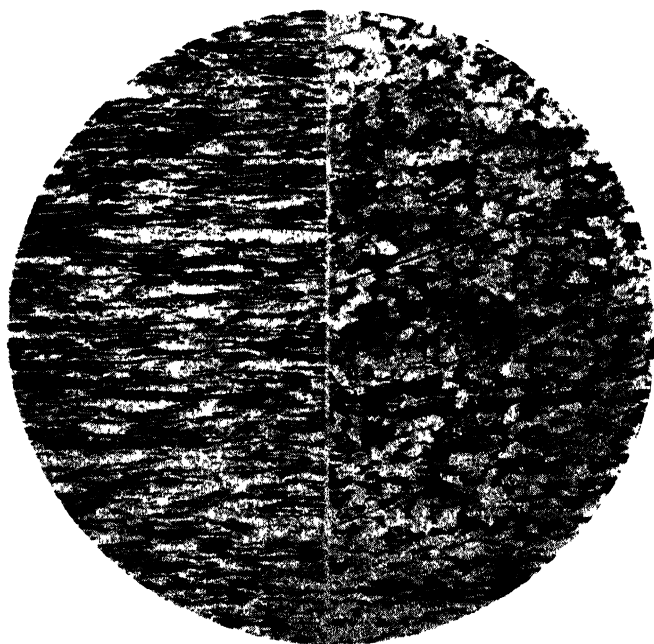
ANNEALING

The size of spangle and the subsequent bending properties of the sheet depend very largely upon the quality of the annealing, and this is not an easy matter to control, as sheets are usually annealed in large packs, hence it is almost impossible to have a uniform time-temperature condition.

For a good tough sheet it is advisable to aim at the

obtaining of a small grain. Fig. 13 is a photomicrograph to 100 diameters magnification showing the structure of a rolled sheet on the left side, and an annealed sheet on the right side.

In Fig. 14 a photomicrograph is shown of a mild steel



(Magnification 100 diameters)

FIG. 13. PHOTOMICROGRAPH OF ROLLED AND ANNEALED SHEET

Showing on the left the rolled structure of steel sheet, and on the other side small crystal grain engendered by annealing

with a large grain, and this, although soft, would not give the same results as the steel whose microstructure is shown on the right in Fig. 13.

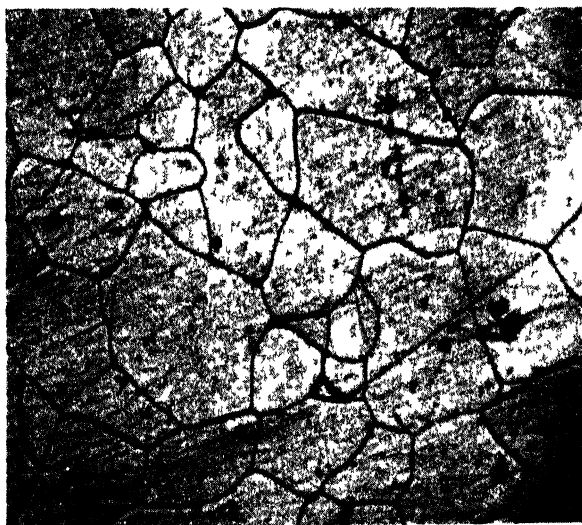
SHEET SURFACE

To get the best results care should be taken that whilst the sheet is properly clean there should be no

over-pickling, as sheets which are over-pickled not only give a small spangle, but take up a larger quantity of spelter, and, of course, use a greater quantity of acid.

QUALITY OF SPELTER

The quality of the spelter is one of the factors which make for the quality of the coat on the sheet. With



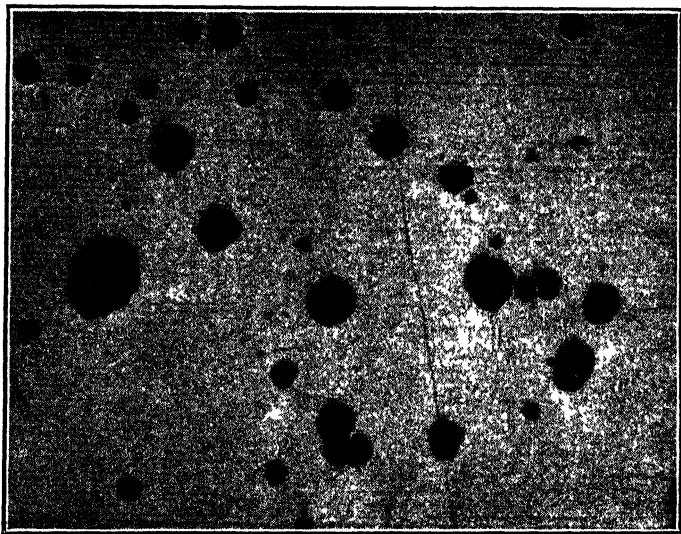
(Magnification 50 diameters)

FIG. 14. PHOTOMICROGRAPH SHOWING LARGE GRAIN THROUGH INCORRECT ANNEALING

electrolytic or pure spelter, it is a curious fact that the best results cannot be obtained. The molten zinc in the galvanizing bath is too viscous, and it is, therefore, necessary to thin it down by the addition of an impure spelter which contains lead. The lead exists in the spelter in minute globules, as shown by Fig. 15. These small globules of lead on the one hand, apparently, form nuclei at which the spangle commences to

crystallize. On the other hand a serious disadvantage in having much lead present in the spelter is that on the sheets, wire, or other articles, it tends to accelerate corrosion.

As will be seen from the accompanying table, iron is always present in commercial spelter, and it usually



(Magnification 100 diameters)

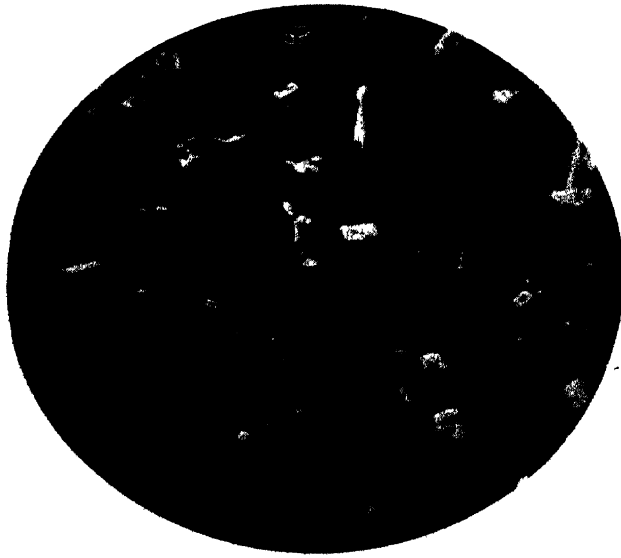
FIG. 15. PHOTOMICROGRAPH SHOWING LEAD GLOBULES
IN SPELTER

exists in the form of the zinc-iron crystals previously mentioned. Typical photomicrographs of spelters containing various amounts of iron are shown in Figs. 16, 17 and 18. The disadvantage of having much iron in the spelter is that it not only increases formation of dross in the bath, but also gives a rough surface on the sheet.

Aluminium is sometimes found as an impurity in remelted spelter, and whilst for the galvanizing of wire under certain conditions the inclusion of aluminium

ANALYSES OF SPELTERS AND DROSS

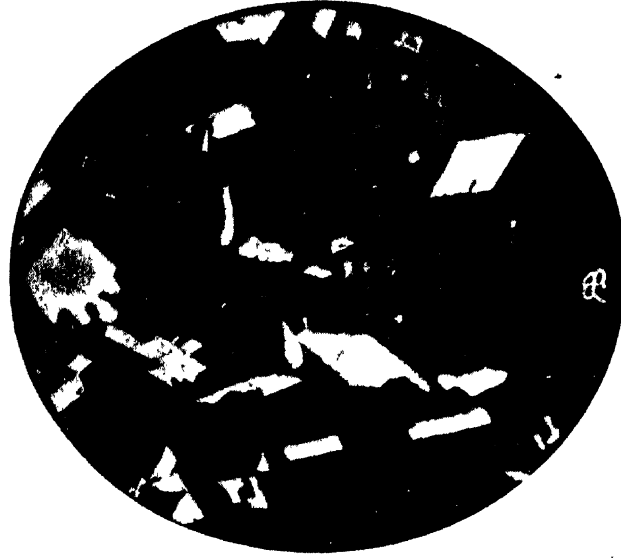
	ELECTROLYTIC			VIRGIN			REMELTED			DROSS	
	Australian	Canadian	Japanese	Belgian	Silesian	American					
Lead percentage .	None	.020	.088	1.18	1.20	1.54	.84	1.20	1.49	1.29	1.14
Iron percentage .	.011	.008	.014	.05	.02	.03	.02	.06	.07	.05	3.80
Tin percentage .	None	None	None	None	None	None	None	.09	.08	.26	None
Copper percentage .	None	Trace	Trace	Trace	Trace	Trace	.02	.06	.05	.07	.03
Cadmium percentage	None	None	None	None	None	None	.52	.15	.20	None	.39
Arsenic percentage .	None	None	None	None	None	None	Trace	None	.02	None	Trace
Zinc (difference) per- centage . . .	99.989	99.972	99.898	98.77	98.78	98.43	98.60	98.44	98.09	98.39	94.64



(Magnification 100 diameters)

**Fig. 16. PHOTOMICROGRAPH OF SPELTER SHOWING
ZINC-IRON CRYSTAL INCLUSIONS**

Spelter contains 0.36 per cent iron



(Magnification 100 diameters)

**Fig. 17. PHOTOMICROGRAPH OF SPELTER SHOWING
ZINC-IRON CRYSTAL INCLUSIONS**

Spelter contains 1.2 per cent iron

may be an advantage, its use in sheet galvanizing is detrimental on account of its floating to the surface of the bath and clogging the rollers. The photomicrograph of a spelter containing 3 per cent of aluminium is shown in Fig. 19. The addition of tin to a galvanizing bath is



(Magnification 100 diameters)

FIG. 18. PHOTOMICROGRAPH OF SPELTER SHOWING
ZINC-IRON CRYSTAL INCLUSIONS

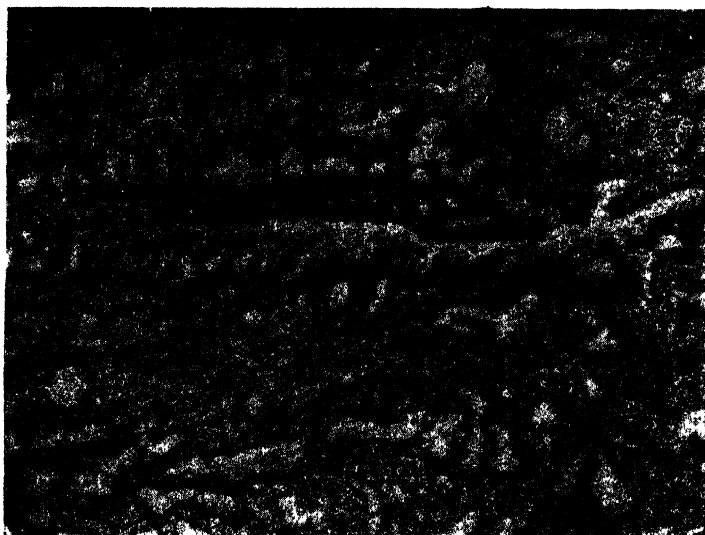
Spelter contains 2.5 per cent iron

an advantage, but it is rather expensive for ordinary practice. Whilst the metal cadmium is now being used for plating purposes and is said to give good results, it is a disadvantage to have it in spelter, as it tends to give a brittle coat on sheets or wire.

TEMPERATURE OF GALVANIZING BATH, AND TIME OF IMMERSION

The melting point of spelter being about $419^{\circ}\text{C}.$, the working temperature of the bath must, of course, be above this. The actual temperature adopted varies

with the kind of work requiring to be done, varying from 435° to 480° C., depending upon the quality of spelter used. A high quality spelter is usually more viscous than low quality spelter, and consequently should be worked at a somewhat higher temperature.



(Magnification 100 diameters)

FIG. 19. PHOTOMICROGRAPH OF SPELTER SHOWING
ZINC-ALUMINIUM ALLOY INCLUSION

Spelter contains 3.2 per cent aluminium

Too low a temperature, as would naturally be expected, gives a heavy coat not too well bound to the steel ; and too high a temperature will give a rough surface on the article and a somewhat brittle coat, and will also tend to form a large quantity of dross through dissolving iron both from the pot and the article to be dipped.

METHOD OF GALVANIZING

The period of time necessary for the article being galvanized to be in contact with the molten zinc will

depend upon the temperature of the bath. Generally, the article should be immersed sufficiently long to form properly the thin film of the zinc-iron alloy upon which can be superimposed the zinc coat. Too long immersion not only results in more iron being dissolved from the surface of the iron or steel, but also tends to give it a rough appearance and a somewhat brittle coat. Too short a time of immersion may result in the coat not being properly formed, or not give sufficient time for the occluded hydrogen of the steel to escape, which will result in a defective coat.

It has already been mentioned that sheets are normally galvanized by passing through submerged and half-submerged rollers, and this method in the main gives a good quality of spangle on the right kind of steel base. But the surface roller method has the disadvantage of trapping a large quantity of the occluded hydrogen (already referred to) which steel takes up in varying degrees, and this hydrogen collecting against the sheet just as it is leaving the bath tends to thin the metal on the surface and cause the sheet not to be properly coated.

With the above method of galvanizing, where the sheet or article is drawn either through a bed of sand on the surface of the bath or through a thin film of fluxing salt, this defect does not obtain.

MATERIALS FOR BATH AND ROLLS

On account of the great dissolving power which zinc has for iron, serious expense and inconvenience is caused by the continual renewal of the baths and the re-building of the surrounding brickwork.

The life of baths is very uncertain, depending upon the quality and condition of the material of which they are composed, the method of heating and possible abuse, and several other factors. A hard-worked sheet

galvanizing bath will occasionally give out in as short a period as three months, whereas an odd-work or wire galvanizing bath will sometimes last from two to four years.

Many efforts have been made to overcome this defect, but up to the present no more efficient means has been devised than to use the most suitable material for the galvanizing bath, to heat it uniformly, and to avoid so far as possible the "washing" of the molten zinc on the surface of the bath. It certainly has been proved that the highest quality of iron or mild steel which has been properly rolled and subsequently normalized gives the longest life, not only for the bath, but the parts of the machinery which are submerged in the spelter.

BY-PRODUCTS OF HOT GALVANIZING

The by-products in connection with the galvanizing of sheets and odd-work are—

1. Hard spelter or dross.
2. Flux skimmings.
3. Zinc ashes or oxide.

In the galvanizing of wire or netting, the first and last only are produced. For economical working, the formation of by-products should be kept at the lowest possible minimum, and this can be accomplished by the adoption of the most suitable means.

EXTENT OF HOT GALVANIZING TRADE

In spite of all the new methods for the surface treatment of iron and steel which have been introduced during the last few years, the business of hot galvanizing covers a large volume of trade, there being approximately 2,000,000 tons of goods galvanized per year in the United Kingdom.

ELECTRO-GALVANIZING

The cold or electro-galvanizing process has made some headway during recent years, and it is possible that for certain classes of work its usefulness may increase. Its advantages over hot galvanizing are—

1. Greater economy in the use of zinc.
2. Complete control over the thickness of coating required up to a certain maximum.
3. The depositing of a coat of pure zinc.
4. Its suitability for articles such as steel springs, etc., which may be affected by the temperature of the molten zinc, if coated by the hot process.
5. No distortion or buckling in the coating of flat surfaces as with the hot process.
6. The carrying out of the process can be done under somewhat healthier conditions than with hot galvanizing.

Its disadvantages are—

1. The time required to coat a surface is much greater than with the hot process.
2. It is very difficult to obtain a thick, non-spongy coat.
3. The coating is usually not as bright as that obtained with hot galvanizing.
4. Much greater care is required, and greater difficulties are encountered to obtain a correct coat than with hot galvanizing.
5. For articles that have to be made watertight, the electrolytic process does not have the same "soldering" effect as the hot process.

In the depositing of zinc by the electrolytic process there is no inner skin of the zinc-iron alloy formed as with the hot process. This will be seen on examining Fig. 20, which is a photomicrograph (to a magnification of 100 diameters) of a part oblique section of a piece of wire. It will be noticed that the coating of zinc is

very thin, and also that it is uniform right up to the steel, showing that no zinc-iron alloy is formed, but that there is, apparently, molecular contact between the zinc and the iron.

To show clearly the difference between the coatings of the hot and cold methods of galvanizing, Figs. 4 and 20 should be closely compared.



(Magnification 100 diameters)

FIG 20. PHOTOMICROGRAPH OF A PART SECTION OF STEEL WIRE COATED BY ELECTROLYTIC GALVANIZING

Many different solutions for the electrolyte are used in connection with the cold process, but the basis of all of them is zinc sulphate.

Steel articles that are electro-galvanized always absorb a certain quantity of hydrogen either in connection with the acid cleaning or the plating. This hydrogen can be quickly driven off if the articles are heated in a steam or gas oven immediately after they are washed. If the articles are not ovened in this way, the occluded hydrogen as it comes from the steel has a

tendency to lift up and blister the coating, and may also result in the development of spots on the surface.

From the point of view of giving out hydrogen after electro-galvanizing, steels vary considerably in this respect. A well-made steel containing few inclusions gives out only a small volume of the gas, whilst steels which contain a large number of non-metallic inclusions will give out a large volume of hydrogen.

When hard steel plates or springs are electro-galvanized, these should be carefully ovened to remove the brittleness which is usually set up by the occluded hydrogen.

The metal cadmium is now being used to some extent to take the place of zinc, the base of the electrolyte being either cyanide of cadmium or chloride of cadmium. It certainly gives a very good coat which stands up to atmospheric corrosive conditions very well, a thinner coat of cadmium being as effective as the heavier coat of zinc.

The disadvantages of cadmium are that it is somewhat dearer than zinc, and gives a rather softer coating; but for fitting purposes where it is essential that the protecting coat should be as thin as consistent with this purpose, cadmium certainly has an advantage over zinc.

SHERARDIZING

This is a process which apparently takes its title from the first name of its introducer, Sherard Cowper Coles. Whilst it has not a great vogue, there are several plants in use in different parts of the country. For fine shaped or screwed articles it has the advantage that it can be effectively coated with zinc without materially altering the shape or dimensions. The cleaning operations in connection with the process are much the same as with hot or electro-galvanizing.

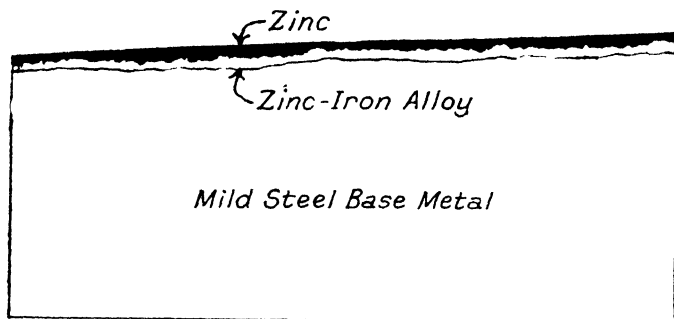
The process itself essentially consists of heating the steel or iron articles which are to be coated in metal drums or boxes whilst being surrounded with zinc dust containing metallic zinc. The temperature to which the articles are heated varies between 350° and 400° C. The higher the temperature the greater is the rate of deposition of zinc on to the surface. From the nature of the method it is obvious that it can be applied only to comparatively small articles. However, it is particularly suitable where a clear thin protection coat is required, and where the pattern or design on the article is to be kept clear or distinct. An illustration of a sherardized coat is shown in Fig. 21.

METAL SPRAYING PROCESS

For many years efforts have been made to coat the surface of iron or steel with metals such as zinc, lead, and copper, without first having to pickle the plate or sheet in acid to remove the scale, or to fix the coating metal by either the hot dip process or electro-plating. A good deal of success in this direction has during the past few years been attained by what is known as the Schoop process. Under this process metal spraying is now carried out very effectively, and coatings of zinc are applied by this process to the inside and outside of tanks, dock gates, and other large structures. In addition, cast iron pipes which are used in connection with the chemical industry are also efficiently coated with lead.

Generally, the process is carried out by first of all sand blasting the surface of the steel to remove the scale, the coating then being applied in the form of a fine spray of molten zinc. In this process the zinc or lead, in the form of a wire or strip, is fed at a uniform rate through the flame of an oxy-hydrogen or other kind of blow-pipe, or through the electric arc, and from this, projected on to the surface which is required to be coated.

In practice a specially prepared metal spray pistol is used for producing the spray. Whilst, of course, the coat is not as firmly adhering as that applied by either the hot galvanizing or the electro-zincing processes, the method certainly offers some promising results in the way of coating large vessels which are fixed in position. It hardly need be said that the metal coating does not alloy with the base metal, but simply



(Magnification 50 diameters)

FIG. 21. REPRESENTATION OF SHERARDIZED COATING

adheres to it in almost the same manner as a coating of paint or varnish.

GALVANIZING TESTS

There is, unfortunately, no simple test which can be applied to a galvanized surface that will, by any means, give an accurate determination as to the possible "life" of the coat under atmospheric or other corrosive influences. This can be readily understood from what has been previously mentioned as to the number of influences which affect the quality of the coat. It is now a well-known fact that a galvanized sheet of wrought iron of the same thickness and weight of coating as a galvanized sheet of mild steel will last considerably longer than the latter when exposed to

the atmosphere, so that quite apart from the quality of the zinc coat, its thickness and method of application, the base metal exercises an important influence in increasing or reducing the life of a galvanized sheet.

There are several tests which are applied to galvanized surfaces to measure their anti-corrosive properties, the best known one being the copper-sulphate test, in which the quality of the surface to resist corrosion is tested by the resistance it offers to the application of a definite copper-sulphate solution for a certain period or number of periods. But, unfortunately, while this test is very largely applied, it gives very little indication as to the suitability of a galvanized surface to stand up against atmospheric influences unless several other important factors are known.

A stripping test is sometimes applied by the application of a 10 per cent solution of hydrochloric acid to the galvanized surface, and recording of the time it takes to remove the zinc coat. It is possible that, under certain conditions, this test gives a better result than the copper-sulphate test.

Even in galvanized sheets the specifying of a definite weight of spelter per square foot does not of necessity carry with it the measurement which the surface offers towards resisting atmospheric influences. The true measure of resistance which any galvanized surface will offer to the corrosive influence of the atmosphere can only be accurately gauged when the quality of the iron or steel base is taken into account, the quantity and quality of the zinc coat, and the method of applying it, but these are not easy to determine.

TINNING IRON, STEEL, AND OTHER METALS

The tin coating of articles made of wrought iron, mild steel, copper or brass, may be carried out in a very simple manner. The articles required to be tinned

must first of all be carefully cleaned, this usually being done by immersion in dilute hydrochloric acid until all scale has been removed. If, however, the articles are greasy, the grease must first of all be removed by immersion in some form of degreasing solution such as hot caustic-soda solution or other form of degreaser. For small articles where there is no degreasing plant handy, grease patches are sometimes removed by heating the article over an open fire previous to pickling.

The size of the pot of molten tin will, of course, depend upon the purpose for which it is used. If small articles have to be coated there is only need for a very small pot in which to carry out the process ; if large articles are to be tinned, or a big quantity of small articles passed through quickly, then it will be necessary to use a larger pot.

For articles to be effectually tinned it is necessary for them to be dipped in a flux solution, and the most suitable for this purpose is a solution of zinc chloride made by dissolving zinc in hydrochloric acid. The articles should be put into the molten metal whilst in their wet state, as the tin will more readily " take " to the surface if the flux is in a moist condition when the articles are plunged into the molten metal.

Whilst articles can be dipped wet in the tinning process, it is exceedingly dangerous to attempt to do this in dipping articles into a galvanizing bath, as on account of the much higher temperature of the latter steam is instantly generated which causes molten zinc to blow out of the bath. Kettles, saucepans, and other kinds of domestic utensils have their interiors tinned, as this metal is not rapidly dissolved away by either vegetable or meat juices as would obtain in the case of uncoated iron, copper or brass. In addition to which, the juices of either fruits or meats in dissolving the metals named will form poisonous compounds.

RE-TINNING ARTICLES

Domestic and other articles after the tin coating has worn away are often re-tinned without being dipped into a bath of molten metal. The inside of the article is carefully scoured and may afterwards be washed out with dilute hydrochloric acid. It is then again washed with water and afterwards covered with a zinc-chloride flux solution. Then if a small quantity of good quality tin is put into the vessel, and the latter carefully heated from the outside, the tin will commence to melt, and by suitably moving the article it will effectually run all over the surface and properly tin it. After the surface is completely coated, and whilst the tin is in a molten condition, it should be wiped over with a whisk of tow. Powdered sal-ammoniac is sometimes used as a flux instead of chloride of zinc solution.

TINNING SHEETS AND WIRE

The coating on sheets to form tinplate and the coating of wire is carried out in the same manner as tinning hollow-ware, except that very special appliances have to be arranged for cleaning, scouring, and carrying forward the steel sheet which is the basis of tinplate. Also, special rollers and other machine parts are used for putting the sheets into the pot, removing them from it and completely finishing.

In tinning wire the process is continuous, the wire after being cleaned and fluxed simply passing continuously through a bath of molten tin ; suitable wipers and boshing arrangement are fixed to the leaving end of the bath.

LEAD COATING

Articles of all kinds can readily be coated with alloys of lead and tin, which coating can much more cheaply

be applied than pure tin, and for some purposes it may be sufficiently good. But alloys of lead and tin should not be used for the inner coating of vessels required for cooking or similar purposes. To coat an article with pure lead cannot easily be done, as at ordinary temperatures lead has so little affinity for iron, but this difficulty is usually overcome by adding from 5 to 10 per cent tin to the lead, which forms an alloy that adheres much more firmly to sheet iron than lead alone would ; this is the method of coating which applies to the making of terneplate.

It is a mistaken notion, however, to imagine that iron cannot be coated with lead, which has resulted in all kinds of patents being taken out to overcome the difficulty of making lead firmly combine with the surface of an iron sheet. There is really no serious difficulty in coating either sheet or wire with lead if suitable precautions are taken to ensure that the wire or sheet is perfectly clean, properly fluxed, and that the lead is at a sufficiently high temperature.

ELECTRO-PLATING

It has already been mentioned that the metals zinc and cadmium can be very effectively applied to iron and steel by the electro-plating method. The metal tin can also be applied in a similar manner, but its application in this way is usually restricted to small articles such as pins, safety-pins, hooks, and eyes, and such-like articles. A very thin coating of tin can also be applied by boiling them in a solution which contains small grains of tin and cream of tartar. The coating so applied is, of course, extremely thin, and really is almost a method of colouring and not of coating. Articles are also coated both with brass and copper by the electro-plating method.

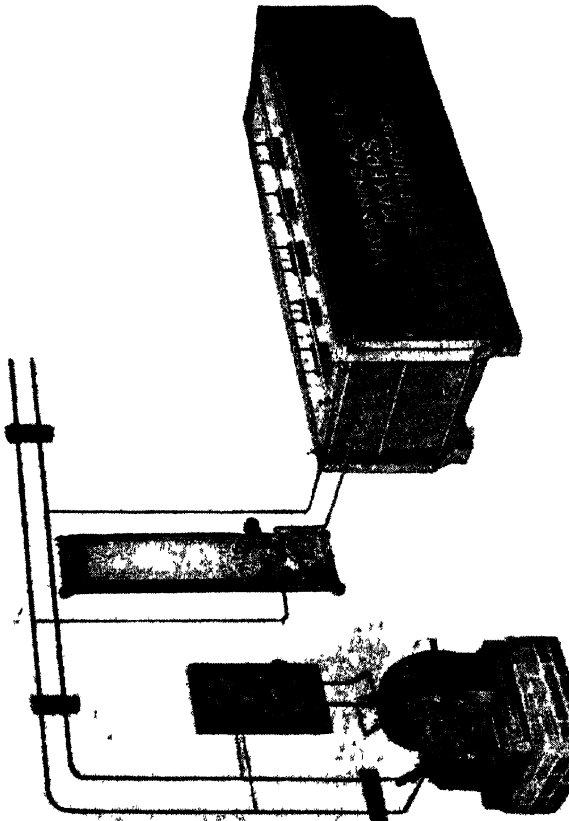


FIG. 22. DIAGRAM OF CONNECTIONS FOR SIMPLE PLATING EQUIPMENT

A shunt regulator is provided in the field circuit of the dynamo, and the voltmeter on the shunt regulator board is connected across the main leads from the dynamo. Anodes are hung on the outer rods at each side of the vat, and the work to be plated is suspended by copper wires from the central cathode rod. The anode rods are connected together and to the positive lead from the dynamo. The cathode rod is connected to the negative lead through an ammeter and a resistance which controls the current flowing through the vat.

Nickel Plating is very commonly in use for coating articles which are to be used for inside purposes only, and when efficiently carried out acts as a fairly good preservative. For outside purposes nickel plating, unless it has been done in a very special manner, offers very little resistance to the corrosion which is engendered by atmospheric influences.

Chromium Plating, after being in the experimental stage for a great number of years, has now been brought to a fairly high state of efficiency, and there is no doubt but that a properly-applied, well-adhering coat of chromium offers the highest resistance to corrosive influences. The metal chromium itself is extremely hard and practically non-corrodible, and now that the difficulties in connection with its depositing are in a fair way to being overcome there would seem to be a great future for the application of this method of coating the inferior base metals.

It would also seem to have a considerable use when applied to the surface of gauges, punches, drawing dies, and various other tools that require their surfaces to stand up against considerable abrasion.

METAL COLOURING AND LACQUERING

By first of all thoroughly cleaning the surface of an article, and afterwards putting it in a suitable dipping solution, all kinds of colours and effects may be obtained, and if these are then coated with a transparent lacquer the results become permanent. Copper, brasses, bronzes, and other metals may be coloured by the use of a suitable dip or lacquer. These are now made up and can be obtained very cheaply to suit all kinds of work and to give all kinds of tints.

Lacquering is sometimes carried out by brushing on large articles, and on small articles by simply dipping.

Transparent lacquers are now very often used for coating articles which are plated either by zinc or cadmium, and which have to pass through workmen's hands in the fitting up of all kinds of plant and apparatus. Where work like this has to be done on articles after they are coated, the application of a hard lacquer keeps the coat of metal from being marked or tarnished by the hands of the workmen, and when metals such as zinc or cadmium are used these are very quickly tarnished by handling.

BLACK ENAMELLING

Black enamelling is applied to a great number of articles, and can be done in either a cheap or expensive form depending upon the purpose for which the article is to be used. Thus iron wire and hoops usually receive one coat, which is applied and stoved as the wire or hoop moves along continuously. For high-class work which is to stand outside exposure, several coats are usually applied after the surface has been carefully prepared. An illustration of this is in the case of bicycle frames and the best kind of enamelled or japanned hollow-ware.

For large articles the enamel is applied with a brush, and the article stoved at a definite temperature for a definite length of time which will give the best results when the enamel is set.

For small articles such as springs, coat hooks, and other forms of fittings the dipping method is applied, the article being dipped in a suitably thin enamel, then allowed to drain before being stoved.

Enamels are now made for all kinds of purposes and to suit all kinds of conditions, and it is essential that an enamel should be chosen that just suits the requirements of any particular case.

VITREOUS ENAMELLING

Vitreous or porcelain enamelling differs from black enamelling inasmuch as the enamel is of quite a different character, and the stoving or baking carried out at a very much higher temperature. Indeed, the temperature for vitreous enamelling must be such that it will fuse the enamel on the surface of the iron or steel and practically flux or burn it on.

A great number of enamels are used in the trade, these being of a very complex character and depending upon the results required. The constituents of an enamel may be borax, alumina, iron oxide, cobalt oxide, soda, saltpetre, chrysolite, quartz, tin oxide, felspar, fluorspar, magnesia, and other substances which may be required to give either colour or certain physical properties.

The old enamellers were in the habit of making up enamels to their own formulae, but in more recent times enamels of all descriptions can be obtained ready prepared and suitable for various classes of work.

The actual operation of cleaning the sheet or other article, the application of the enamel either by the wet or dry process, and its correct stoving has to be carried out with a good deal of care if the results are to be of a high standard.

When the base metal is sheet iron or sheet steel it should be selected with care, as with some inferior qualities of mild steel it is absolutely impossible to obtain good results. The composition of a suitable sheet steel should be somewhat as follows—

Carbon	.	.	.	.	·10
Silicon	.	.	.	.	Trace
Sulphur	.	.	.	.	·04 max.
Phosphorus	.	.	.	.	·04 max.
Manganese	.	.	.	.	·25–·35

The chemical composition, however, of a sheet steel for enamelling should not be the sole guide as to its

usefulness for the purpose, as in addition to being the right chemical composition it should be a clean steel, i.e. free from any abnormal amount of non-metallic inclusions, also copper, tin, and arsenic. It should also have a high class surface, care being taken that this is not spoilt in the pickling or cleaning operation.

CALORIZING AND COSLETIZING

Mild steel and iron articles are calorized in a somewhat similar manner to the way they are sherardized except that aluminium powder and alumina are used instead of zinc and zinc oxide. The process forms an iron aluminium alloy on the surface of the article covered with a thin coating of alumina. Articles so treated are used to resist the action of high temperatures in the presence of oxidizing gases, and for the tubes in water-tube boilers and similar purposes, considerably lengthening their life.

Cosletizing is a chemical process which consists of immersing the iron in a hot phosphate solution. The surface, the inventor claims, is converted into a ferros-ferric phosphate which, under certain conditions, acts as a resistant to corrosion. It is used for the preliminary treatment of steel and other articles before blacking, and when so used adds considerably to the resisting power of the surface against corrosive action.

BARFING AND OTHER OXIDIZING METHODS

A number of processes which depend upon the production of a fully oxidized surface on iron or steel, such as that which is obtained on the well-known Russian iron, have been in use for several years. Among these are the Barf and the Bower processes.

The two processes mentioned and others of a similar

character are carried out with a view to producing a thin film of magnetic oxide on the surface of iron or steel. When iron is properly treated in this way and taken care of it will last a considerable time without corroding. In the Barf process the articles to be coated are heated to $538^{\circ}\text{C}.$, and steam which is super-heated to $280^{\circ}\text{C}.$ is injected into the coating chamber. In the Bower process, producer gas rich in carbon monoxide is said to reduce the red oxide obtained by air treatment or by subjecting the work to acid fumes.

By the Bower-Barf method, articles to be coated are heated in a closed chamber to $466^{\circ}\text{C}.$, after which super-heated steam is injected which forms a firm coating of the black magnetic oxide.

Whilst sheets or plates of this description are used for stove pipes, casings, etc., care has to be taken in bending them for fear of fracturing the hard oxide coat.

ANODIZING PROCESS FOR PROTECTING SURFACES OF ALUMINIUM ALLOYS

The process of anodizing aluminium and its alloys consists, in its simplest form, of building up an oxide film on the surface of the metal, sometimes known as anodic oxidation, that will resist the corrosive action of salt water, sea air, and certain atmospheres that have been affected by manufacturing processes where acids and chemicals are present. It is generally known that in some circumstances aluminium is liable to corrosive deterioration unless some protective coating is given to the surface of the metal. Ordinary painting will not suffice; on the contrary, painting may prove a source of danger by preventing corrosive deterioration being discovered in time to prevent fracture occurring.

A method of oxidizing or anodizing was introduced to increase by electrolytic means the natural film of

aluminium oxide that is found to exist, to an infinitesimal degree, on the surface of the metal, and which to some extent tends to resist any further natural atmospheric oxidation, and it has been stated that the first artificial oxidation of commercial value to be carried out was by Bengough and Stuart, who were granted a British Patent for their process. In this instance a solution of chromic acid was used as an electrolyte, and the aluminium article to be oxidized, or anodized, was used as the anode in this solution, a vat or tank being used as in the case of ordinary plating. They also observed the dyeing capacity of the oxide film, which allows certain colours to be dyed into the oxides, and which is now being rapidly developed in connection with ornamental ware.

Much progress has been made in anodizing methods during the last few years, and many firms engaged in the manufacture of aluminium alloy parts have installed anodizing plant to carry out the process as a normal part of their business. The methods adopted vary in some respects and many patents have been taken out for particular processes, some of these being available for use under licence. So much importance is now attached to anodizing that it is now specified as a treatment for aircraft parts constructed in aluminium alloy. It has been stated that anodic films obtained by the chromic and sulphuric acid process will withstand at least 12 months intermittent salt spray, when the parts have been impregnated with lanoline or a similar oil or grease.

The commercial importance attached to anodic oxidation may be gauged by the fact that it is now possible to obtain fully automatic control generators for the purpose, so that to a large extent the process of anodizing may be made automatic.

SECTION XXVI

GEAR CUTTING

BY

H. E. MERRITT

D.Sc., M.I.Mech.E., M.I.A.E.

SECTION XXVI

GEAR CUTTING

INTRODUCTORY

TOOTHED gears form an indispensable element in mechanical construction, and with the ever-growing demand for higher speeds and quieter running the manufacture of gears has become an increasingly refined and specialized art. In the beginnings of the development of the mechanical arts several types of gear, now obsolete, were introduced, and a common form was the "cog" wheel in which the teeth proper were made of suitable timber, such as hornbeam or apple, individually fastened in recesses spaced around the periphery of the body of the gear. Such teeth were, of course, formed by hand and the profiles given to them were determined by the individual fancy of the millwright. The next stage was represented by the introduction of "cast" gears in which the tooth form was cut by hand in the pattern and reproduced in cast iron by moulding. Machines for carrying out the moulding operation were subsequently developed, and for many grades of comparatively crude machinery "machine-moulded gears" are still employed.

With the general increase in the running speeds of machinery, the inevitable inaccuracies of cast gears gave rise to so much difficulty in regard to noise of operation, and tooth breakage through impact loading, that improved means of securing accuracy were sought, and these formed the starting-point in the development of innumerable types of gear-cutting and tooth-finishing machines.

SPUR GEARING

Spur Gearing is the simplest of all forms of gearing, and from it most other forms have been developed. When the principles underlying the design and production of spur gearing are thoroughly understood, other types of gear present little difficulty.

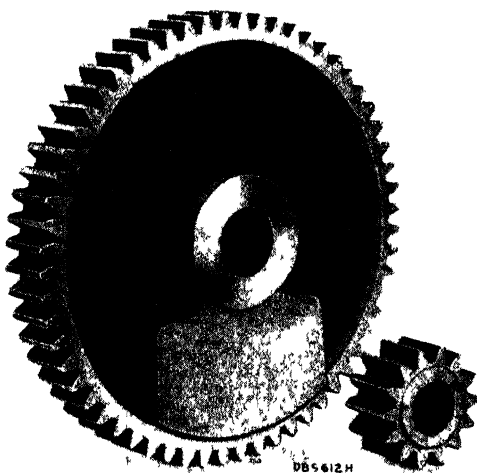


FIG. 1. PAIR OF SPUR GEARS

Spur gears consist of cylindrical wheels connecting parallel shafts, and have straight teeth parallel to their axes; a typical pair of such gears is shown in Fig. 1. In order to approach the question of the cutting of the teeth it is necessary to understand something of the design and action of the gears.

Tooth Curves. The question of the best form to be given to gear teeth has always been a controversial matter. The first essential is that the tooth profiles shall be so chosen that they transmit uniform angular

velocity ratio from one shaft to another, and there are an infinite number of combinations which satisfy this requirement. The type of tooth curve originally employed was the "cycloid," but for various practical

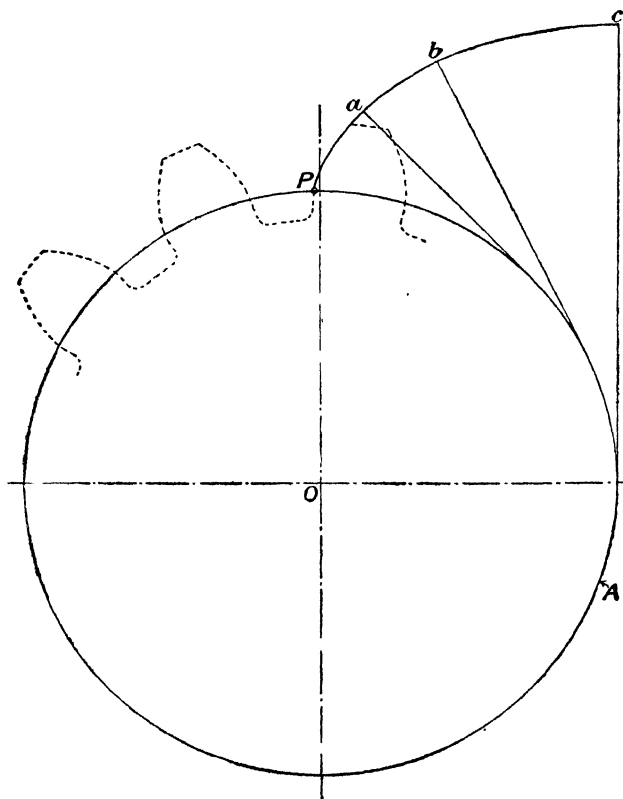


FIG. 2. DEVELOPMENT OF AN INVOLUTE CURVE

reasons this form of tooth is now almost entirely obsolete, and has given place to the "involute" system. This curve is produced in the following manner.

Imagine that round the cylinder represented by the circle *A* in Fig. 2 a thin steel band is wound, its free end

being at P . Now imagine the free end to be unwound, the free portion being held quite taut. Then since the other end of the band is fixed to the cylinder at some point, the free end will trace out a curve $Pabc$, and this curve is called the "involute" of the circle A , which is known as the "base circle" of the involute. This curve could be used as the working profile of a gear tooth, and dotted lines have been added to Fig. 2 to show what the appearance of the final tooth would be.

The use of involute curves for the working profiles of gear teeth is accompanied by two important advantages. Firstly, not only do the teeth, if accurately made, transmit constant angular velocity ratio when the gears are mounted at the theoretically correct centre distance, but they also retain the same property even although the centre distance be changed; this property is not shared by any other form of tooth. Secondly, an involute curve may be "generated," in a manner which will be described in more detail later, from a straight line, and this facilitates accurate manufacture of gear generating cutters, and also accurate measurement of the gear teeth themselves.

Tooth Elements. The uniform motion which gears are intended to transmit is the same as would be given by two smooth cylinders if they were made to roll together by friction without slipping. Fig. 3 shows a pair of gears, some of the teeth of which have been replaced by these imaginary cylinders. Since there is no slip, the teeth of both gears must be spaced the same distance apart round these cylinders and the distance between similar faces of successive teeth on either gear measured round the cylinder is called the "pitch." The circles representing the cylinders are called "pitch circles," and their respective diameters are the "pitch diameters" of the gears.

The pitch of the teeth is expressed in any of three

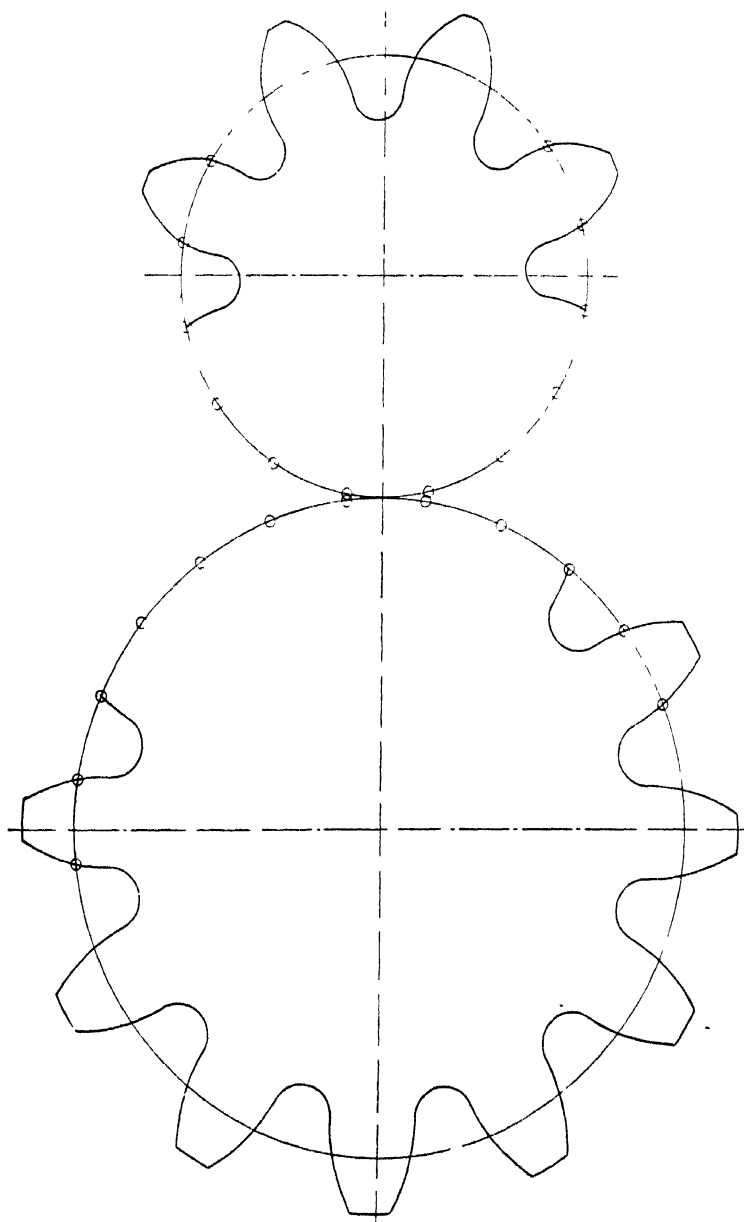


Fig. 3. $\sqrt{\text{PITCH CIRCLES OF SPUR GEARS}}$

ways. *Circular pitch* is the simplest and is as defined above—the distance between similar faces of successive teeth measured round the pitch circle. *Diametral pitch* is found by dividing the number of teeth by the pitch diameter, usually giving a whole number; thus, if the pitch is said to be 8 D.P. it means that there are eight teeth for every inch of pitch diameter. The *module*,

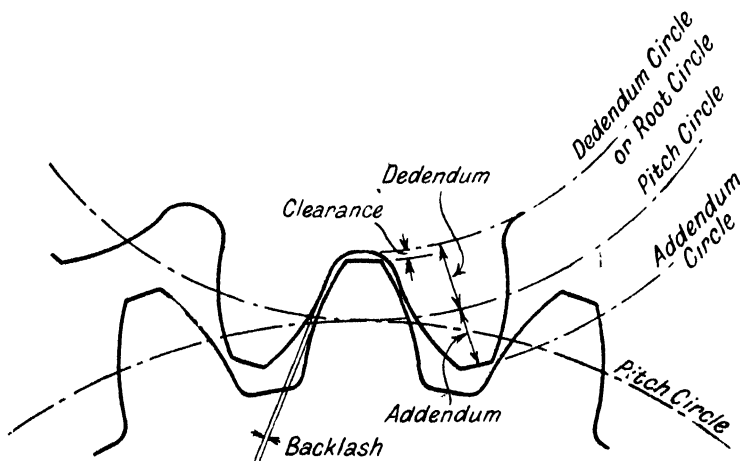


FIG. 4. NOTATION OF SPUR GEAR TEETH

used in Continental and sometimes in British practice, is found by dividing the pitch diameter by the number of teeth, and is thus equal to $1 \div \text{diametral pitch}$.

Addendum, Dedendum and Clearance. The addendum is the height of the crest of the tooth above the pitch circle, and the dedendum is the depth of the root of the tooth below the pitch circle. The sum of the addendum and dedendum therefore gives the whole depth of the tooth, and this is the depth which the cutter must be sunk into the work. Fig. 4 shows the teeth of two gears in mesh and the names given to the various parts of the teeth can most readily be gathered from the illustration. *Clearance* is necessary to prevent the

crests and roots of the teeth from becoming wedged together if the centre distance is not quite accurate and also to permit the root of the tooth to be rounded for strength; similarly, *backlash* must be provided to permit the gears to rotate freely in the presence of variations of tooth thickness and pitch.

Tooth Proportions. Considerable difference of opinion has existed in the past in regard to the proportions which should be adopted for gear teeth. A system once greatly in vogue was that associated with the use of Brown & Sharpe rotary milling cutters, in which the addendum was made equal to 0.3183 times the circular pitch and the dedendum 0.3683 times the circular pitch, giving a clearance of 0.05 and a whole depth of 0.6866 times the circular pitch respectively. These proportions were combined with a pressure angle (*vide* the following paragraph) of $14\frac{1}{2}$ degrees.

In addition to these proportions, innumerable other systems have been introduced by firms manufacturing gear-cutting machines, but it is now generally admitted that whilst the working depth (twice the addendum) of the Brown & Sharpe system is satisfactory, the pressure angle and clearance are both too small, the former because it leads to excessive undercutting when used in conjunction with generating processes, and the latter because it gives insufficient fillet radius. Consequently, the proportions given in British Standard Specification No. 436/1940 may be taken as representing much better practice. These are briefly as follows—

Addendum = $1.0 \div \text{diametral pitch}$

Dedendum = $1.25 \div \text{diametral pitch}$

Clearance = $0.25 \div \text{diametral pitch}$

Pressure Angle. Contact between the teeth of a pair of involute gears always takes place along a line called the *path of contact*. This line is the straight line which is a tangent to the base circles of the gears and the angle

which it makes with the tangent to the pitch circles is called the *pressure angle*. This sounds complicated, but is actually very simple, as Fig. 5 will show. It is necessary to know what the pressure angle of a pair of gears is to be, because a gear cut with a cutter of, say, $14\frac{1}{2}$ degrees will not mesh correctly with another cut by means of a cutter of the same pitch but having a pressure angle of 20 degrees.

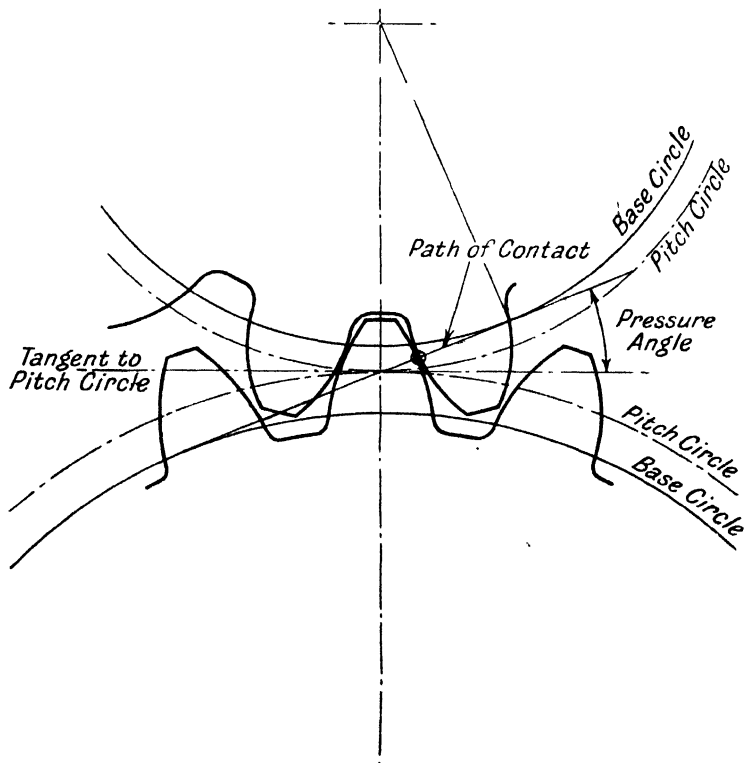


FIG. 5. PRESSURE ANGLE OF SPUR GEARS

PRINCIPLES OF GEAR CUTTING

Forming and Generation. All known methods of cutting the teeth of gears of every type can be placed

under either one or other of the two headings, "forming" and "generation."

Forming processes are methods, such as could be developed in any workshop, for finish machining the teeth to a certain predetermined profile by means of suitably shaped cutters, forming tools or copying mechanisms.

Generation, on the other hand, consists in the production of the teeth by means of a cutter which itself has teeth corresponding in profile to those of an actual gear wheel. While the cutter is in operation, a "rolling-generating" motion takes place between the wheel to be cut and the gear to which the cutter corresponds. This "rolling-generating" action is sometimes a little difficult to follow, and will be dealt with in more detail later.

Rotary Cutters. Rotary milling cutters were the first tools used to form the teeth of gears. They consist of circular cutters suitable for mounting on the arbor of a milling machine and having cutting edges corresponding in profile to the space between two teeth.

Fig. 6 shows a rotary cutter in the process of cutting. The "blank," as the uncut wheel is termed, is mounted on a dividing head, the cutter having first been adjusted so that its centre line is truly radial with respect to the blank. If this is not done the teeth will not, of course,

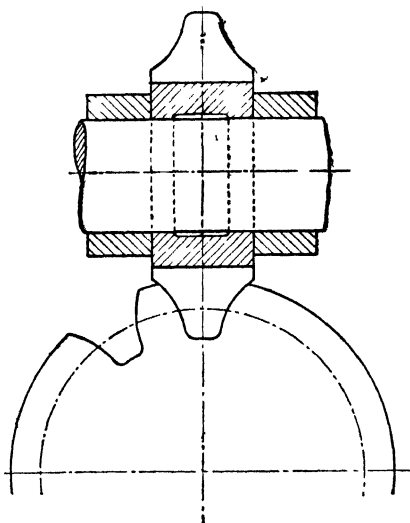


FIG. 6. CUTTING SPUR GEARS BY ROTARY CUTTER

be symmetrical. The cutter is then lowered until the teeth just scrape the blank ; the dial of the machine is set to zero, the blank is withdrawn, the cutter is fed to the depth of cut required and the feed mechanism is engaged to cause the blank to be traversed past the

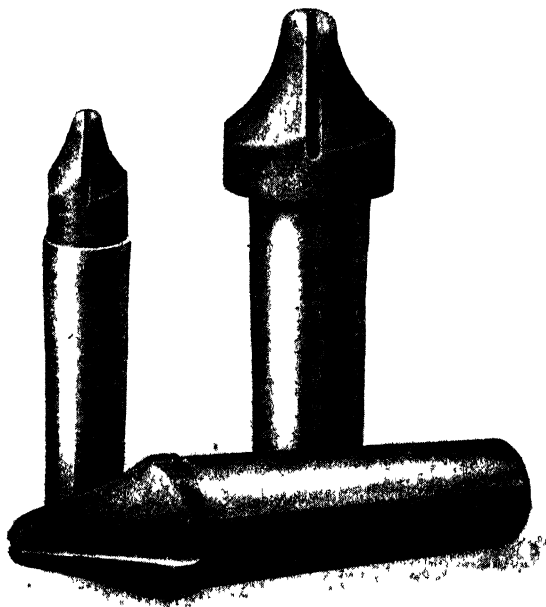


FIG. 7. GROUP OF END-MILLING CUTTERS

cutter, thus completing a roughing cut on one tooth space. The blank is then withdrawn and indexed to the next tooth space and the cycle of operations is repeated. When all the teeth have been roughed out (sometimes a special cutter is used for this purpose) the cutter is sunk to the full depth and the finishing cuts are taken.

End-mill Cutters. For cutting the teeth of gears of very large pitch, such as 6 or 8 in., the cost of even

a disc-form rotary cutter becomes prohibitive, and end-milling cutters are used. Except for the fact that the axis of rotation is differently situated, end-mill cutters work in the same way as rotary milling cutters. Typical end-mills are shown in Fig. 7.

The end-milling process has been extensively employed for the cutting of "helical" and "double helical" gears, and will be described in this connection later.

Templet Processes. This term may be applied to the machines which produce the tooth profile by means of a reciprocating single-pointed tool. In addition to its reciprocation, the tool is caused to trace out the profile by means of a former or templet and a copying mechanism.

GENERATING PROCESSES

The Fellows Gear Shaper. The generating process easiest to understand is the gear shaper process first developed by the Fellows Gear Shaper Co. In this process the cutter has the form of a pinion, the details of its shape being most easily followed from the illustration (Fig. 9).

Fig. 8 shows how the cutter is used, the example shown being the cutting of the teeth of an internal gear, to which the process is peculiarly well adapted. The cutting action is provided for by the reciprocation of the cutter in a vertical direction; in addition to this the cutter and the blank are slowly rotated about their respective axes. The speeds at which these rotations occur correspond exactly to the rotation of the internal gear with a pinion having the same number of teeth as the cutter, consequently the cutter in its rotation will "generate" tooth profiles on the blank. These tooth profiles will necessarily be different from the profiles of the cutter teeth themselves, but will, of course, give

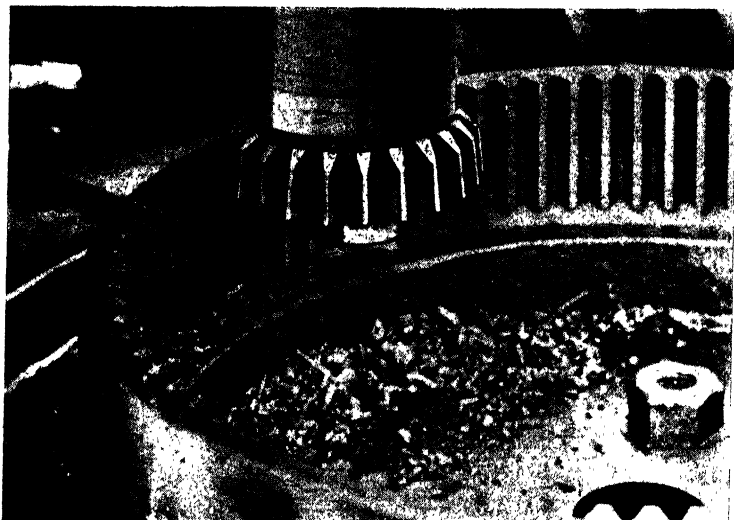


FIG. 8. CUTTING AN INTERNAL GEAR

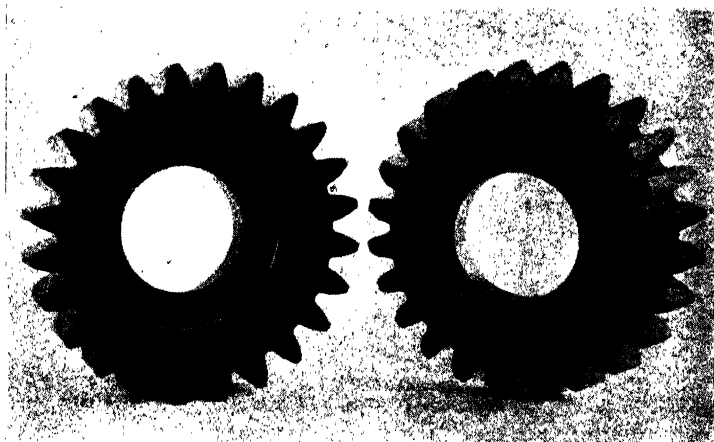


FIG. 9. GEAR-SHAPER CUTTERS

correct tooth action with a pinion of the same shape as the cutter.

If the internal would mesh correctly only with this one pinion, the process would not be of much value, but owing to another feature of the involute system *all gears cut with the same generating cutter mesh correctly together.*

Herein lies one great advantage of a generating system: only one cutter need be used for each pitch, whereas rotary cutters have no such latitude of application. Actually a rotary cutter is correct only for the number of teeth for which it is designed, and where in practice one cutter is made to cover a range, the gears at the extremity of the range are necessarily inaccurate. At the same time, the gear shaper process is much faster than rotary cutting.

Fig. 10 shows a pair of high-speed gear shapers. These machines have a cutter speed of up to 600 strokes per min., and this combination of high speed and fine feed produces a very good tooth surface.

The Rack Planing Process. This process, due to Sunderland, and often known by his name, makes use of the fact that the "rack"—i.e. the gear of infinite radius—of the involute system is composed entirely of straight lines. Fig. 11 shows an involute rack and pinion. The teeth of the rack have straight sides inclined at the pressure angle to the line of centres, and can therefore be easily manufactured and, what is very important, can be ground to exact form after hardening.

The rack planing process makes use of a cutter of rack form which reciprocates in the same way as a gear shaper cutter. Whereas the gear shaper cutter derives its generating action from simple rotation; however, the rack cutter requires a more complicated cycle. The sequence of movements is shown in Fig. 12.

The rack cutter being set in reciprocation and the



Fig. 10. PAIR OF FELLOWS HIGH-SPEED GEAR SHAPERS

blank being stationary, the cutter is fed forward until it touches the blank, so that the dial can be set to indicate the depth of cut. The cutter is then fed into the

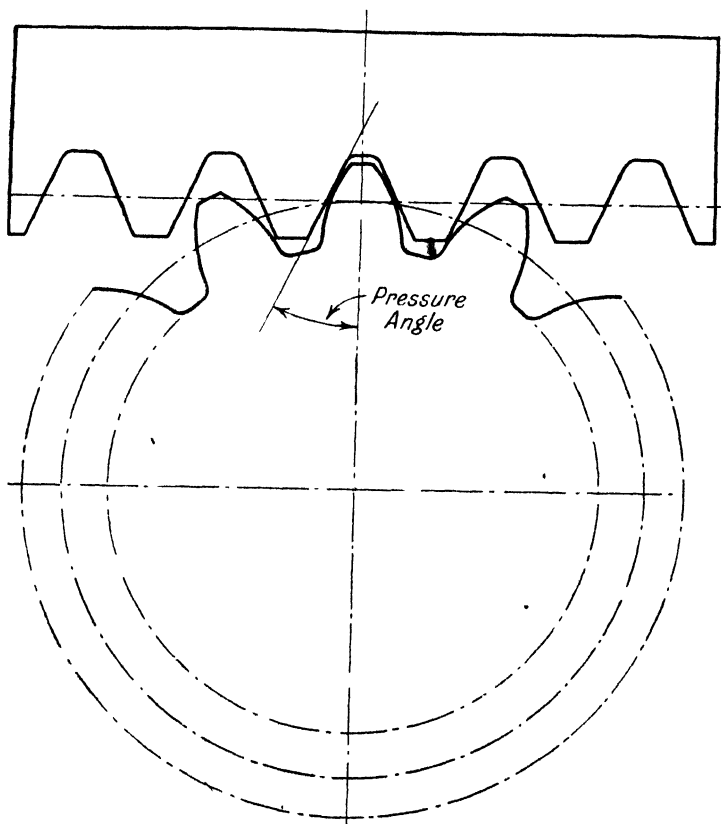


FIG. 11. INVOLUTE RACK AND PINION

blank by the desired amount (perhaps for a roughing cut of half the total depth) and the rolling-generating motion then begins. This consists of a slow, uniform, rotational movement of the blank, whilst at the same time the cutter slide and cutter all move in the

direction of the pitch-line of the cutter. The speeds of these two movements are so related by means of the gearing of the machine that the pitch-line speed of the rotating blank is equal to the speed of translation of the cutter. That is to say, if the blank were regarded

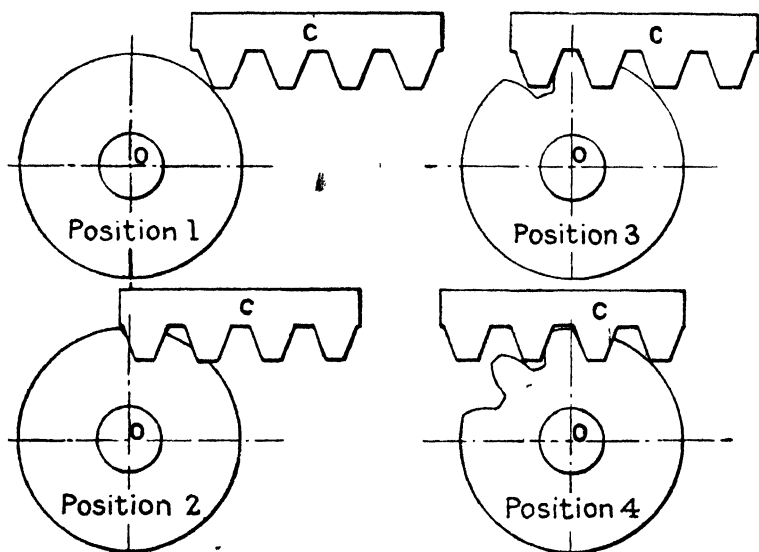


FIG. 12. CYCLE OF OPERATIONS IN GENERATING BY RACK CUTTER

as finish-cut and the cutter were stopped from reciprocating, the two would "roll" together in just the same fashion as the gear and its rack (to which the cutter corresponds) would do.

When the cutter and blank have thus rolled a distance equal to one pitch the blank ceases its rotation, and the cutter (while continuing to reciprocate) is withdrawn and returned, in the direction of its pitch-line, to its starting point. It is then fed to depth and the cycle of operations is repeated in the manner

described until every tooth is cut. Such further roughing cuts as may be necessitated by the pitch of the gears to be cut and the hardness of the material are then taken in the same way, followed by the finishing cut, when the cutting is completed.

The first of a batch of blanks is always set up, and a cut, just scraping the surface, is taken in order to verify that the machine has been set up to cut the correct number of teeth.

In the "Sunderland" machine manufactured by Messrs. J. Parkinson & Sons, Ltd., Shipley, the work is mounted on a horizontal arbor and the cutter reciprocates in a horizontal direction when cutting spur gears. The cutter head is, however, inclinable, so rendering the machine suitable for cutting gears with spiral teeth.

A similar principle, but different mechanical arrangement, is adopted in the "Maag" spur and spiral gear generating machine illustrated in Fig. 13. Here the work is mounted either on a horizontal table or on a vertical arbor attached to it; the cutter reciprocates in a vertical direction for spur gears and in an inclined direction when cutting spiral teeth. This machine has a number of interesting features the object of which is to secure the highest attainable precision; one of the most important of these lies in the indexing mechanism. Instead of the cutter being returned exactly one pitch, it is returned by a slightly greater amount, and is then moved forward again just before cutting. In this way backlash is taken up and a possible source of error is eliminated.

THE HOBGING PROCESS

This process is sometimes erroneously described as an elaboration of the rack process, but this is not so. It is in principle entirely different from both the rack and gear shaper processes.

In order clearly to appreciate the distinction, it may be pointed out that in the gear shaper process the blank is "rolled" with what is actually a spur gear, whilst in the rack cutter process the blank is rolled with a

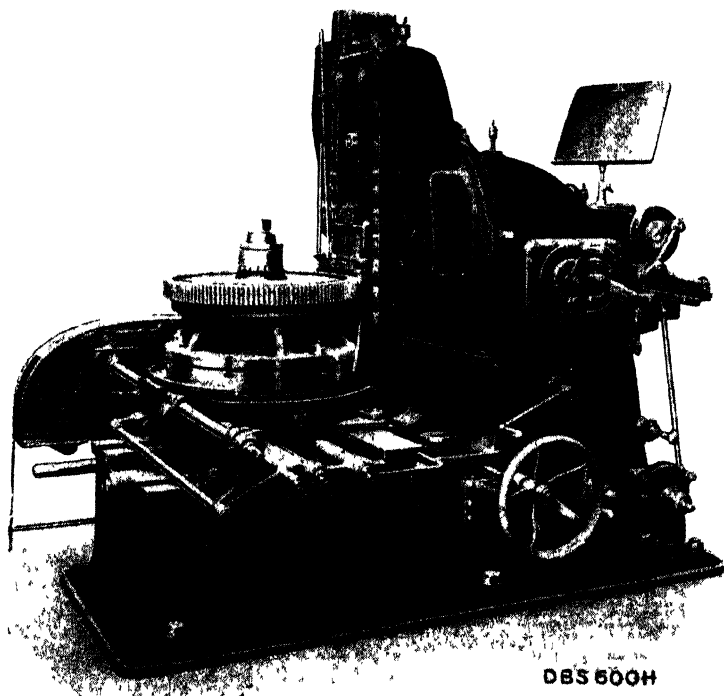


FIG. 13. "MAAG" SPUR AND SPIRAL GEAR GENERATING MACHINE

rack. In the hobbing process the blank is rolled with a rotating *spiral gear* having cutting edges. This cutter is termed a *hob*, and a typical example is shown in Fig. 14.

The use of a hob is based on the valuable property of the involute system, already mentioned, that all

involute gears cut with the same rack cutter will mesh correctly together. A spiral gear can be cut with a rack cutter by the Sunderland process; if this gear be provided with relieved cutting edges it becomes a hob and can be made to produce involute gears, both spur and spiral, which will also mesh with any gears produced by the original rack cutter. In practice it

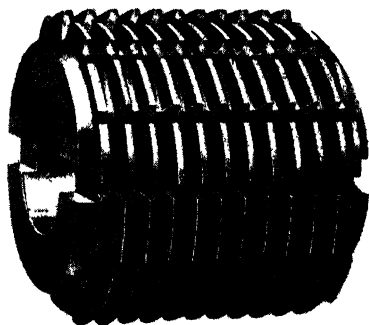


FIG. 14. TYPICAL GROUND HOB

is usual to produce a "single-start" hob as a screw by means of a relieving lathe.

In cutting a spur gear with a hob (see Fig. 15), the blank is mounted on the work spindle and the hob on the hob spindle, the latter being inclined so that the hob threads are parallel to the axis of the blank in the region where cutting takes place. The hob and work spindles are then connected by gearing of such a ratio that, if the hob is a "one-start" hob (i.e. all the cutting teeth lie in a single helix or spiral), it makes one revolution for every pitch that the blank rotates. The hob then generates teeth on the blank when suitably

fed into the work, and in order to complete the teeth from end to end the hob is caused to travel, in addition to its rotary motion, across the face of the blank in the direction of the teeth.

The hobbing process has a number of advantages.

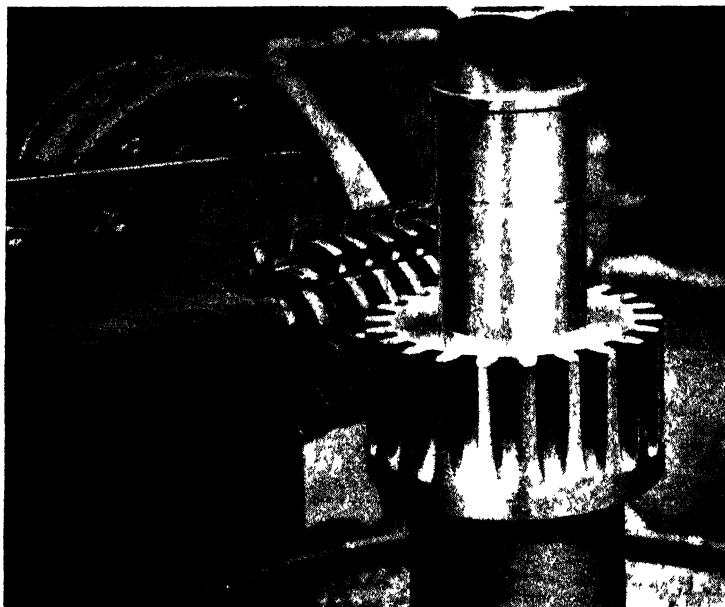


FIG. 15. HOBBIING A SPUR GEAR

Firstly, it is a continuous process ; there are no reciprocating parts and no time is lost in return cutting strokes or in indexing. Secondly, the hob has a large number of cutting edges, thus reducing the frequency with which sharpening is necessary. Further, there is less risk of variation in tooth thickness, since the cutting action has no definite starting and stopping places. On the other hand, the finish produced is not as good as that of the Sunderland and Fellows processes, since

each hob tooth cuts only at a "spot" instead of along a line.

THE PROFILE GRINDING OF GEAR TEETH

In order to secure the highest load carrying capacity it frequently becomes necessary to use hardened materials, and to counteract the effect of distortion in heat treatment a further finishing operation is necessary after cutting and hardening have been completed. The most important of these operations is that of profile grinding. This may be carried out according to one or other of the two principles already described in connection with gear-tooth cutting, namely "forming" and "generation." In the "formed-wheel" process, principally developed by the Gear Grinding Co., Ltd., an abrasive wheel trued by cam-controlled diamonds to the desired shape of the tooth space is used in a manner similar to an ordinary rotary cutter, with the exception that a machine specially designed for the purpose is employed.

Profile grinding by generation is represented by a variety of machines such as the Maag, Lees-Bradner, Pratt & Whitney, and others. In all these an abrasive wheel virtually sweeps out the plane surface of the basic rack, past which the gear to be ground rolls in much the same way as when generated by means of a rack-type cutter. By way of illustration, Fig. 16 shows the grinding wheels of a Maag machine in operation on a helical pinion. These wheels are saucer-shaped and have their axes inclined at the pressure angle so that when viewed in the direction of the tooth spiral they occupy the positions of opposite sides of one tooth-space of a rack. The wheels grind only along their edges, and in order that they may sweep out the full plane surface of the basic rack the work is fed longitudinally past them, in addition to being given a

rolling motion controlled by means of tapes fastened to a cylindrical pitch block.

In the case of the Lees-Bradner machine, illustrated in Fig. 17, the abrasive wheel is large in diameter and grinds on a flat face, so that when grinding gears of a

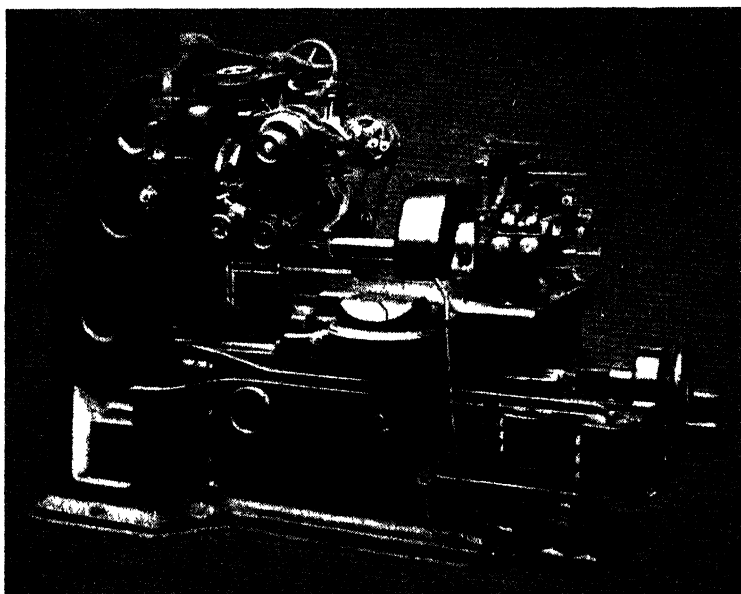


FIG. 16. MAAG GEAR-TOOTH GRINDING MACHINE

comparatively narrow face-width (for which the machine is designed) it is necessary to give the blank only the rolling motion, this being derived from a master gear, similar to that being ground, engaging with a stationary rack.

In the case of the Pratt & Whitney machine, the abrasive wheel is of trapezoidal section and is reciprocated at a fairly rapid rate in a direction parallel to the axis of the work, which again derives its rolling motion from a master gear and rack.

LAPPING

Lapping is a process whereby gears are run together in pairs under load, an abrasive paste or compound being introduced between the teeth in order to remove small surface irregularities from hardened gears, in

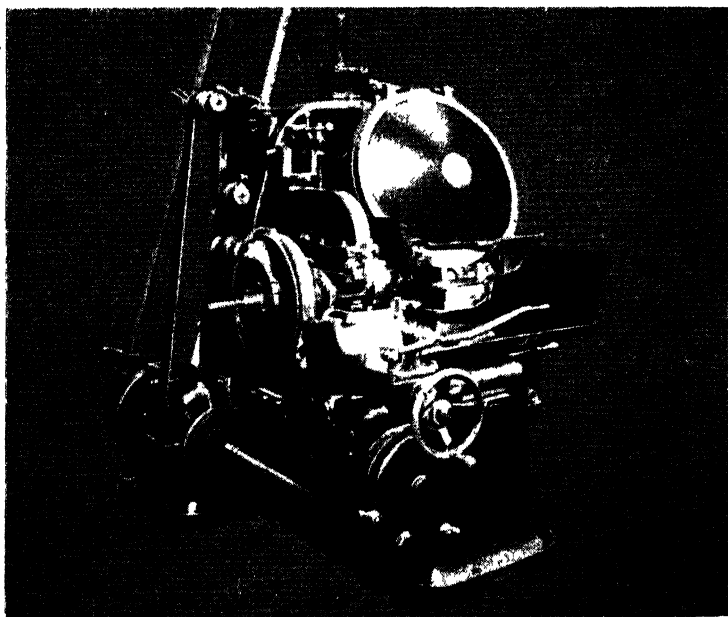


FIG. 17. LEES-BRADNER GEAR-TOOTH GRINDING MACHINE

which distortion has been reduced to a minimum by the use of quenching dies and close metallurgical control. It is a very dangerous process, except where very judiciously used. It may make good gears slightly better, but makes bad gears worse, and if its use is attempted with soft materials there is the further risk that abrasive may remain embodied in the surfaces and lead to rapid wear.

The above remarks apply only to the lapping together of a pair of mating gears in their running position, and it should be noted that this system of removing material from gear-tooth surfaces has been successfully developed with the aid of special machines whereby a gear is lapped by running it with a lapping wheel, having a different motion from that with which the gear to be lapped will ultimately run. In one case the lap is given, in addition to its rotation, a rapid axial reciprocation which has the effect of more nearly equalizing the rate of removal of the material. An alternative system is that of "crossed-axis" lapping in which the gear to be lapped is run with a lapping gear wheel running on an inclined axis. This introduces a longitudinal sliding which enables the lap to remove material in a more uniform manner over the profile of the teeth.

BURNISHING

This is a process, for which a variety of machines are available, for improving the surface finish and uniformity of gears after cutting and prior to hardening. It consists in rolling the soft gear between hardened and ground master gears under a load sufficient to produce a smooth surface by cold working.

GEAR-TOOTH SHAVING

An alternative method of finishing gear teeth in the soft state is by means of a "shaving" process. In such processes the tool is in the form of either a gear or rack, and in addition to being hardened and accurately ground, the tooth surfaces are provided with a large number of very fine serrations, thus forming cutting edges in the surface. The gear is forced into contact with the shaving tool, and the relative motion, which is very similar to that of a generating machine, causes

the cutting edges of the tool to remove a large number of very fine shavings and leaves the teeth in a highly-finished condition.

The machine introduced by the Michigan Tool Co. makes use of a tool in the form of a built-up rack having inclined serrated teeth, over which the gear to be finished is rolled backwards and forwards. The gear axis being inclined to the direction in which it rolls, the teeth have a longitudinal sliding motion relative to the rack, from which the cutting motion is derived. Alternatively, the finishing tool may be in the form of a helical gear, as developed by the National Broach and Machine Co., and in this case the longitudinal sliding or cutting action is derived from the fact that the axis of the tool is inclined to that of the work.

UNDERCUTTING IN GENERATED GEARS

The phenomenon of "undercutting" is of great importance and, although one which belongs to the design rather than the production side of gearing, should be understood by those who are concerned only with production in order that any blame for the bad tooth shapes which are often met with can be correctly apportioned.

Undercutting is a result of incorrect design, and only at that stage can it be avoided. If too small a number of teeth is cut in a blank, the involute portion of the curve is mutilated by another curve traced out by the corners of the generating cutter. For example, Fig. 18 shows the tooth profile of a ten-tooth pinion cut with a $14\frac{1}{2}$ degree pressure angle cutter, standard proportions. The involute curve can extend only down to its base circle—not below it—and this base circle is very close to the pitch circle. The actual dedendum of the gear extends much below the base circle, and consequently

the tip of the cutter sweeps out a curve at the root of the teeth which actually cuts away part of the involute.

The "Interference Point." Fig. 19 shows a rack cutter generating a pinion in the extreme position which will avoid undercutting. In this diagram PI is the "path of contact" inclined at the pressure angle.

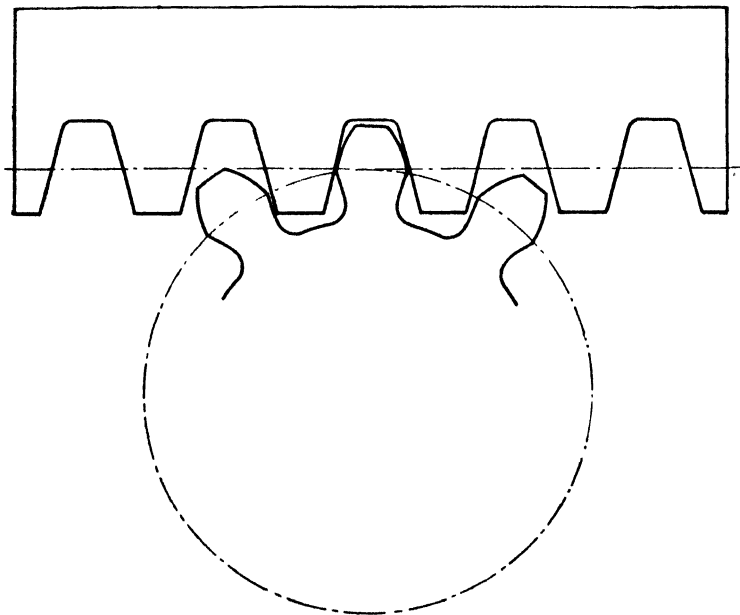


FIG. 18. SPUR GEAR WITH UNDERCUT TEETH

This is the line along which contact between the involute portions of the finished teeth and the rack takes place, and it is a tangent to the "base circle" at I . Provided that the corner of the rack cutter does not extend beyond I , no undercutting will occur; and the point I is called the "interference point" because if the rack cutter extends beyond it the root curve "interferes" or cuts away the involute above the base circle.

Undercutting commences at thirty-two teeth if the pressure angle is $14\frac{1}{2}$ degrees, and seventeen teeth for 20 degree pressure angle—in each case for full standard depth of tooth. If the number of teeth is less than the above the teeth will be undercut.

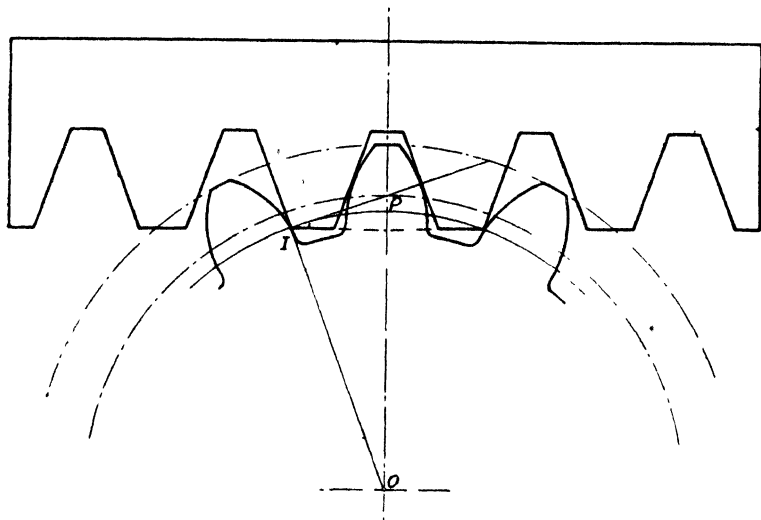


FIG. 19. LIMIT OF CUTTING TO AVOID INTERFERENCE

Correction for Undercutting. There are four principal ways of avoiding, or “correcting” for, undercutting.

The first consists in choosing a higher pressure angle, which moves the interference point nearer the centre of the gear and enables a larger dedendum to be used. Thus, if twenty teeth are to be cut, they would be badly undercut if made with $14\frac{1}{2}$ degrees pressure angle, but would be quite satisfactory with 20 degrees pressure angle.

The second method consists in using “stub teeth,” i.e. teeth with smaller addendum for a given pitch. This method is not satisfactory; it gives a slight increase in strength but reduces the wearing area of the teeth.

The third method consists in altering the disposition

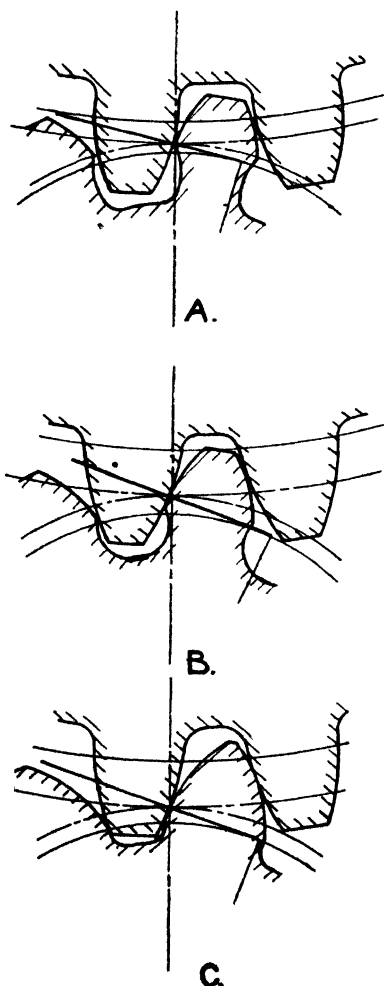


FIG. 20. METHODS FOR AVOIDING UNDERCUTTING

of the teeth relative to the pitch circle. In the case of a pinion with a small number of teeth, undercutting can be avoided by reducing its dedendum and increasing its addendum to correspond. At the same time, if the number of teeth on the wheel is sufficiently large, the addendum can be reduced and the dedendum increased without fear of undercutting. These alterations can be easily carried out and the gears will run correctly and at the proper centre distance if the teeth are cut to the correct total depth and thickness.

Fig. 20 shows the effect of the application of the first and third methods to a pair of gears having ten and forty teeth. At A the teeth have been cut with $14\frac{1}{2}$ degrees pressure angle and the pinion is

badly undercut. By increasing the pressure angle to 20 degrees, as at B, much, but not all, of the undercutting

disappears. By the addition of addendum correction as at *C*, undercutting is entirely eliminated.

The fourth method is termed the "extended centres" system and is used when both the wheel and pinion have a comparatively small number of teeth. In this case the addenda of both wheel and pinion are increased and the centre distance is increased to correspond. This system gives very good tooth shapes, but it is necessary to reduce the depth of tooth slightly in order to maintain the correct clearance.

GAUGING INVOLUTE SPUR GEARS

It may be taken as an axiom in gear manufacture that the more accurately gears are cut the more smoothly they will run. Although the tooth form is often modified from the theoretical involute in an attempt to compensate for other errors, the nearer the approach to theoretical form, combined with accurate pitch, the better the results.

The first measurements taken of teeth while they are being cut, however, are to determine the thickness of the teeth. Fig. 21 shows a tooth and the dimensions usually measured. The tooth flanks intersect the pitch circle at the points *aa*, the pitch circle being represented by the arc *aca*. For a pair of gears of equal tooth thickness, the length of the arc *aca* is equal to one-half the pitch, minus half the backlash. The distance along the chord, or straight line *aa*, is, however, less than this. It is usual to calculate the length of this chord for an arc of one-half the pitch and to subtract one-half the backlash from the result. The method of making this calculation involves trigonometry, but tables of corrections are given in machinists' pocket-books.

From Fig. 21 it will also be seen that the distance of

the measured chord from the top of the tooth is a little greater than the addendum. In the diagram bc is the addendum and cd is the "height of arc" of aca and the measured distance, or "height setting," is $bc + cd$

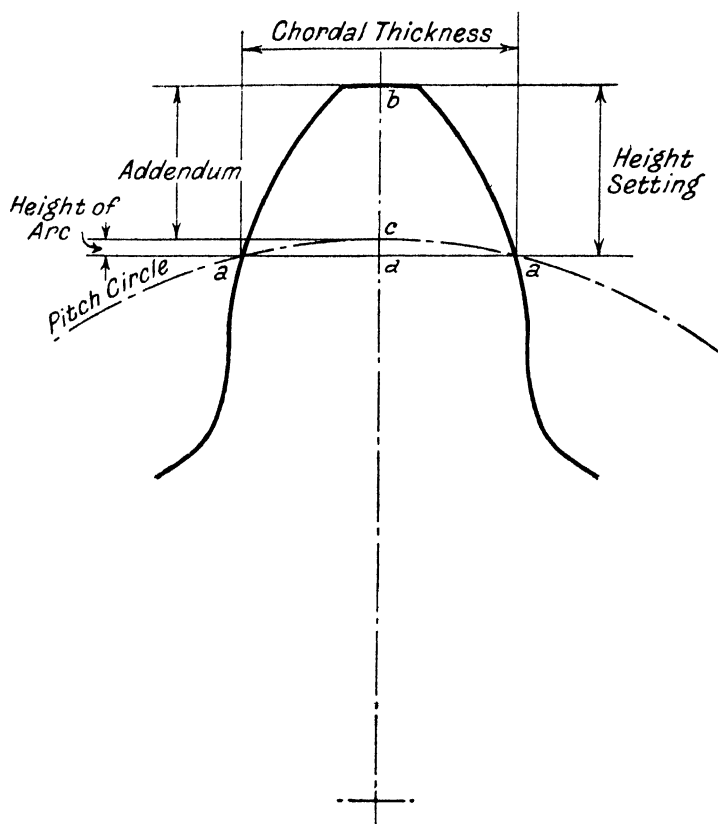


FIG. 21. CALIPERED DIMENSIONS OF A GEAR TOOTH

$= bd$. When measuring an actual tooth the outside diameter of the blank is first measured so that any error in this dimension can be allowed for in measuring the tooth thickness.

Fig. 22 shows the instrument, called a "gear tooth vernier" used for this purpose. It consists of two jaws the distance between which can be measured to .001 in. by means of a vernier scale. In addition the jaws are recessed and a straight edge slides up and down between

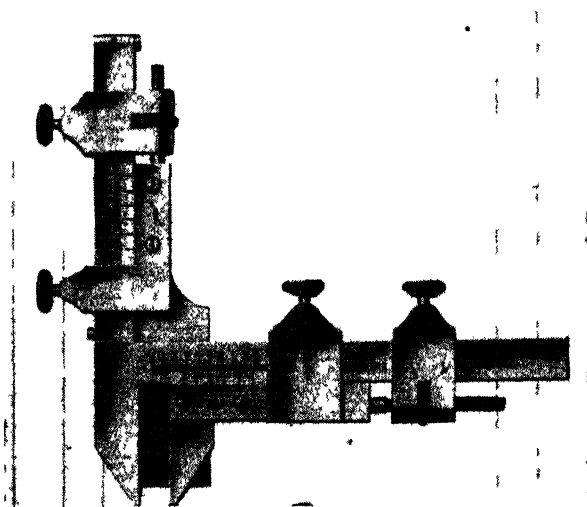


FIG. 22. GEAR TOOTH VERNIER CALIPER

them, its position being given by a second vernier scale which shows the distance from the straight edge to the corners of the jaws.

Pitch Errors. Testing for accuracy of pitch is an operation which cannot be carried out on the machine, but must be referred to the inspection department.

There are two chief methods which may be employed. The first consists in mounting the gear on a spindle which can be rotated with precision through any desired angle, and bringing a gauging point into contact with the tooth flank. After an initial reading has been

taken the gear is turned exactly one pitch ; a second reading in this position should give the same result as the first. If it does not do so, the difference is the amount of error in pitch. This process, repeated for every tooth, shows the "accumulated" error, or error of each tooth from its correct position.

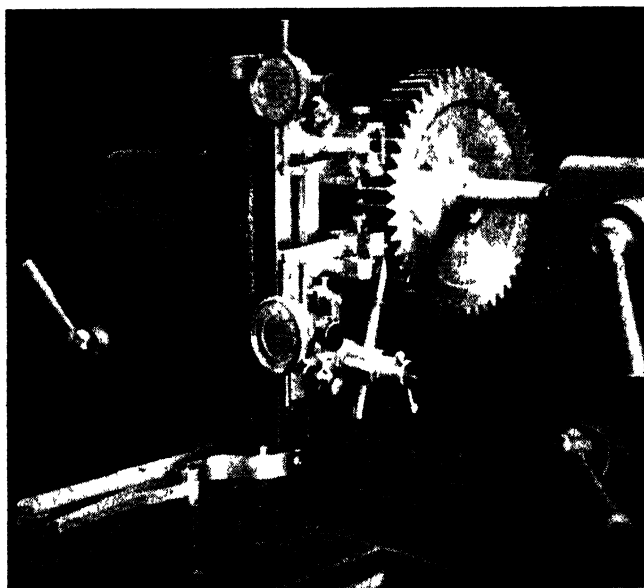


FIG. 23. INSTRUMENT FOR MEASURING
PITCH ERROR

The second method consists in measuring the spacing of each pair of teeth in turn, thus determining the "adjacent" pitch errors. These are added, usually graphically, in order to obtain the accumulated error. A "David Brown" instrument for this purpose is shown in Fig. 23, and consists of two measuring points, each operating a dial indicator, one of which is brought to zero ; the variation is then read off on the other.

Profile Errors. Errors in profile can be measured in various ways, which generally come under one of two headings, *mechanical* and *optical*. Mechanical methods involve giving the gear a rolling motion past a gauging point in such a way that the point describes an involute curve relative to the gear. The usual method is to

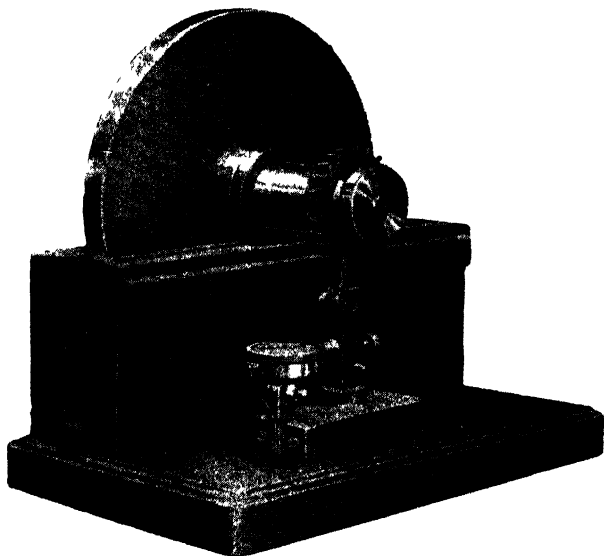


FIG. 24. MECHANICAL METHOD OF GAUGING INVOLUTE PROFILE

attach a disc to the gear, the diameter of the disc being made equal to the base diameter of the gear, and rolling the gear and disc along a straight edge. The gauging point is mounted in the plane of the straight edge and a dial gauge indicates movement of the gauging point. If the pointer does not move the profile is correct. Fig. 24 shows a fixture for this purpose.

The simplest optical method consists in projecting an enlarged image of the tooth on to a screen and

comparing it with an accurately drawn enlarged profile mounted on the screen. Alternatively, an outline may be obtained on smoked glass by a copying mechanism,

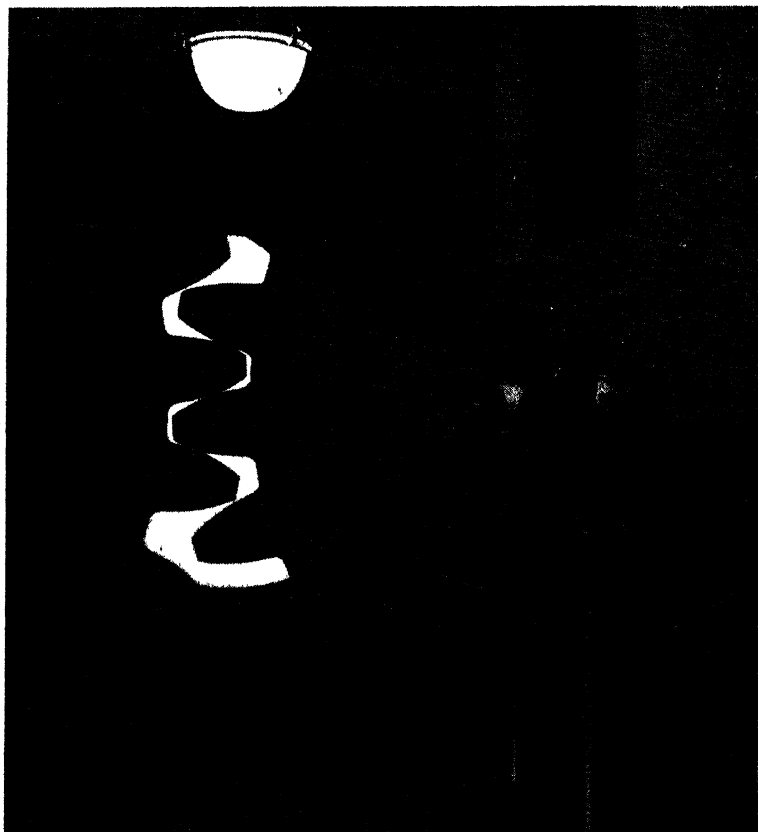


FIG. 25. OPTICAL PROJECTOR FOR GAUGING
TOOTH PROFILE

and this outline projected ; but this is more a laboratory than a workshop method. Fig. 25 shows an optical projection instrument designed for gauging gear teeth profiles.

SPIRAL GEARING

A straight-sided rack meshes with a spur gear of the same pitch when the rack teeth are parallel to the gear axis. If, however, the teeth of the rack are inclined to the axis of the gear, the latter must have spiral teeth, and is called a "spiral gear" or a "helical gear," according to the way in which it is used. In either case the same principles hold good.

Fig. 26 shows diagrammatically the rolling of a spiral gear, over a rack; in this diagram, for clearness, the teeth are not shown but only the centre lines of the teeth. In diagram (a) each tooth appears as a helix, but if the pitch surface of the gear be developed—i.e. opened out until it lies flat—each helix becomes a straight line. The distance between the centre lines of adjacent teeth, measured at right angles to the teeth, is called the "normal pitch," and is equal to the pitch of the teeth of the rack cutter.

The angle between the tooth and the axis is called the "spiral angle," and the complement of this angle is the "lead angle." The "lead" is the distance advanced by a tooth along the axis in one revolution.

Production of Spiral Gears. Each of the processes already described in connection with spur gearing can be applied, with suitable modification, to the production of spiral gearing.

If the rotary milling cutter process is to be used, a cutter of the appropriate normal pitch is selected and mounted on the arbor of a universal milling machine. The profile of the cutter to be used depends upon both the number of teeth and the spiral angle of the gear to be cut. The table of the machine is then swung over to the spiral angle and the work mounted in a dividing head geared up to the lead of the threads, and a tooth space is then milled. After indexing, the process is repeated until all the teeth are cut.

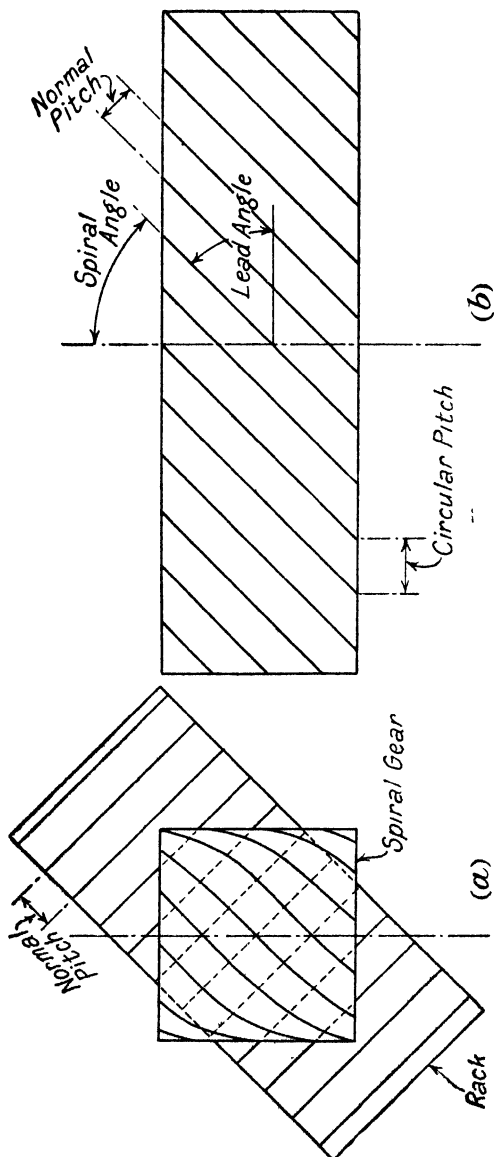


FIG. 26. ROLLING A SPIRAL GEAR OVER A RACK

Generation by "Sunderland" Process. Spiral teeth can be generated by a rack cutter in exactly the same way as spur gears; all that is necessary is to select a cutter of the desired normal pitch and incline the direction of reciprocation of the cutter at the spiral angle. The rolling mechanism must, however, be set up for the circular pitch.

Generation by "Fellows" Process. This process does not permit the latitude in spiral angle possible with either rack planing or hobbing. The circular generating cutter must reciprocate in a direction parallel to the axis of the blank, and it must therefore have teeth inclined at the same spiral angle as the blank. Consequently the cutter must reciprocate with a spiral motion of which the lead is fixed; this lead is obtained by means of helical guides. Apart from the helical motion of the cutter the process is exactly the same as for spur gears.

Generation by Hobbing. The hobbing of a spiral gear is perhaps more difficult to understand than the same process applied to spur gears.

The hob to be used must have the same normal pitch as the spiral gear to be cut, and when mounted in the machine the direction of cutting must be parallel to the teeth of the gear. The hob spindle must therefore be adjusted to the appropriate angle, which is equal to the spiral angle of the gear, plus or minus the lead angle of the hob threads, according to whether the gear and the hob are of the same hand or of opposite hands—the former is to be preferred.

Next, the speeds of rotation of the hob and the work must be so timed by the "index change gears" that for every pitch advanced by the hob threads the blank rotates one pitch, as in the case of spur gears.

Finally, a differential motion must be given to the rotation of the hob through the intermediary of

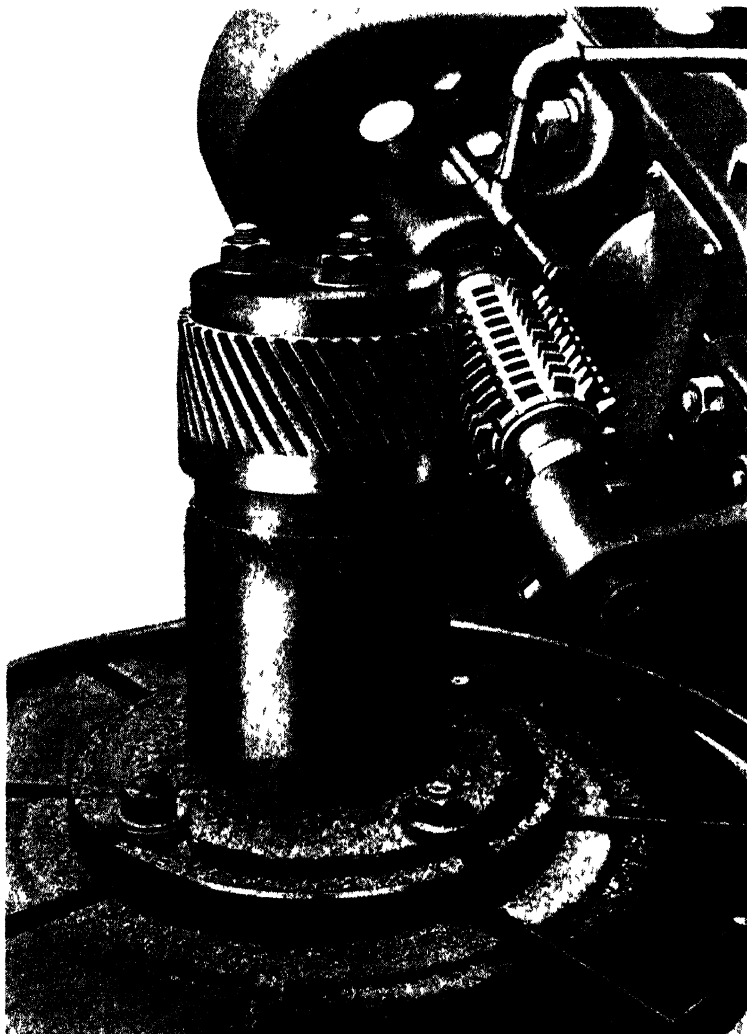


FIG. 27. HOBGING A SPIRAL GEAR

“differential change gears.” The differential mechanism is so arranged as to make the hob increase or decrease its rotation as it is fed across the face of the work. To understand this differential motion, regard the hob and blank as having ceased to rotate. Then let the hob be fed across the face of the blank. Owing to the spiral form of the teeth it will be necessary for the hob to “roll” in order that its threads may fall correctly into the tooth spaces of the gear being cut. The differential change gears are calculated to give just this motion, and the differential mechanism adds this motion to the rotary motion of the hob and the blank independently of the rate of feed. Fig. 27 shows a spiral gear in process of being cut.

Undercutting of Spiral Gears. Undercutting can and does occur with badly designed spiral gears. It is not quite so liable to occur, for reasons which will be explained; when it does occur it can be obviated by a change in design according to one of the methods given under the heading of “Spur Gearing.”

The Virtual Spur Gear. If a cross-section of a spiral gear tooth be taken, it will be found to be different from that of a spur gear of the same pitch and number of teeth, the extent of the difference being greater or less according to the spiral angle. Whatever the tooth shape of a spiral gear may be, however, depending upon the spiral angle, it is possible to find a spur gear having some larger number of teeth which will have approximately the same profile. For example, a spiral gear having ten teeth and a spiral angle of 45 degrees will have the same profile, very nearly, as a spur gear of the same pitch and normal pressure angle, but with twenty-eight teeth. This spur gear is called the “virtual spur gear” corresponding to the assumed spiral gear. To find the number of teeth in the virtual spur gear, the number of teeth in the spiral gear is multiplied by

the cube of the ratio of the circular pitch to the normal pitch. Incidentally, it follows that if a rotary milling cutter is used to cut the teeth, the same cutter is used as would be suitable for cutting the virtual spur gear.

Gauging Spiral Gears. With the exception of optical projection, all the methods used for gauging spur gears can be applied to spiral gears with practically no alteration. The gear tooth caliper is the instrument most frequently used, and the height and thickness settings are calculated for the virtual spur gear.

HELICAL GEARING

Object of Helical Gearing. In ordinary spur gearing, in which the teeth are parallel to the axis of the gears, the conditions of tooth contact at any moment are the same at every point along the length of the teeth. Thus a fresh tooth comes into action simultaneously along its whole length, and passes out of engagement in the same way. Owing to the inevitable machining errors, the drive cannot therefore be entirely smooth; and, furthermore, since the rate of wear is different at different points over the profile of the teeth, the drive will become still more non-uniform as time goes on and the teeth begin to wear.

The teeth can, however, be made helical, i.e. each tooth will form a helix or spiral round the pitch cylinder. Provided that the spirals of the engaging teeth are of the same angle and opposite hand, and that the tooth contours are correctly formed, the gears will mesh correctly.

Under these conditions several pairs of teeth may be in contact at the same instant, the actual number depending upon the spiral angle, whilst between each pair of mating teeth the line of contact is a short diagonal line extending from top to bottom of the

teeth. Such gears give very much smoother running, and the effect of tooth wear does not have the same adverse influence upon the uniformity of the transmission.

End Thrust of Helical Gears. The inclined direction of the tooth load gives rise to a certain amount of end thrust; this can either be reduced by using a small spiral angle and employing thrust bearings, or it can be balanced out by dividing the face width into two portions of opposite hand. Such gears are termed *double-helical* gears. In some cases the face width is divided into three portions, two right-hand and one left, and vice versa for the mating wheel. This latter type is known as *triple-helical gearing*.

Cutting Helical Gears by Forming. The forming process, using end-milling cutters, was the first process used in cutting helical gearing. A machine constructed by the firm of David Brown & Sons (Huddersfield), Ltd., for cutting heavy rolling mill pinions is shown in Fig. 28. For such heavy gears this process is the most economical, since the cutters are much cheaper than any other kind of cutter—generating cutters or hobs, for instance—would be.

In order to produce helical teeth, the cutter rotates for the cutting action, and at the same time is traversed mechanically along the bed of the machine. If the blank is held stationary a spur gear results; but by rotating the blank through suitable gearing in proportion to the travel of the cutter a helical tooth space is cut. At the centre of the face width the direction of rotation of the blank is automatically reversed, and the other half of the face is thus formed with a helical tooth of opposite hand.

The end mill process gives a continuous tooth, i.e. there is no gap at the centre. The portion near the apex, however, whilst possibly contributing a little to the strength of the gear, does not give a continuous

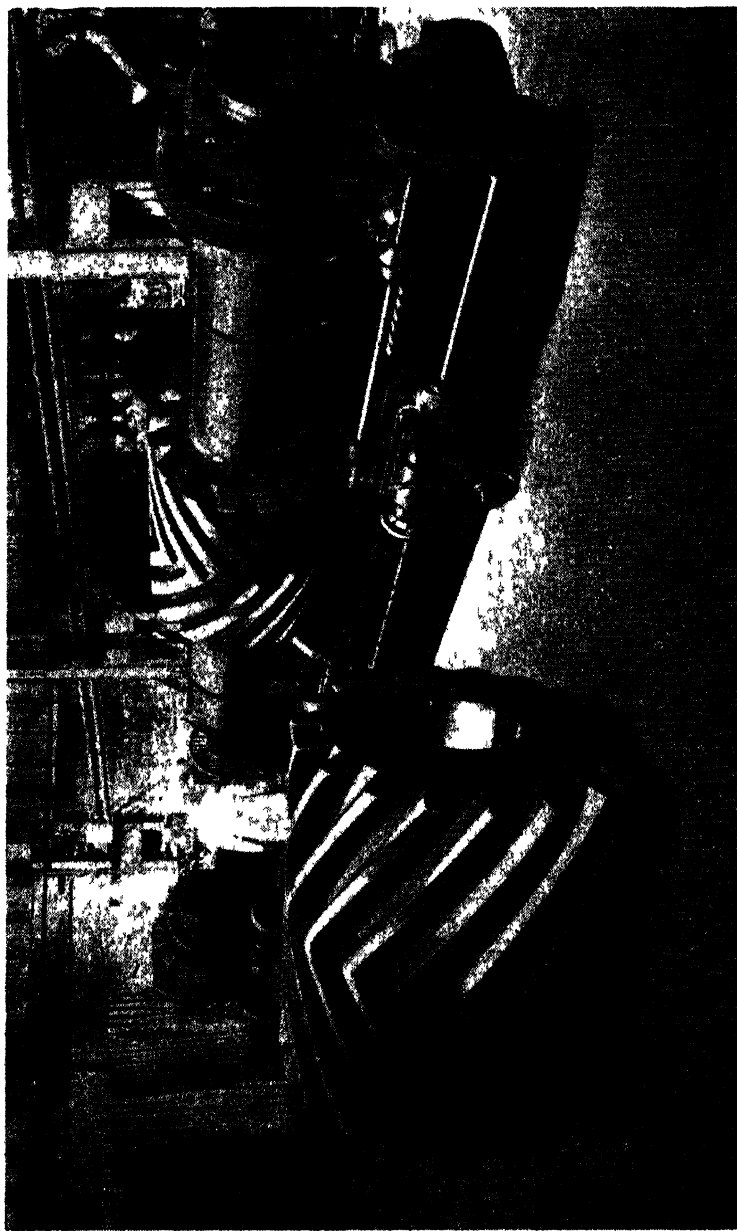


FIG. 28. "DAVID BROWN" MACHINE FOR CUTTING ROLLING MILL PINIONS

bearing surface, about half a pitch being lost when the sharp corner left by the cutter is rounded off.

The Sunderland Process. The rack planing process, already described in connection with spur gears, has been applied in a very ingenious manner to the production of double-helical gears, with continuous teeth having the entire face-width effective.

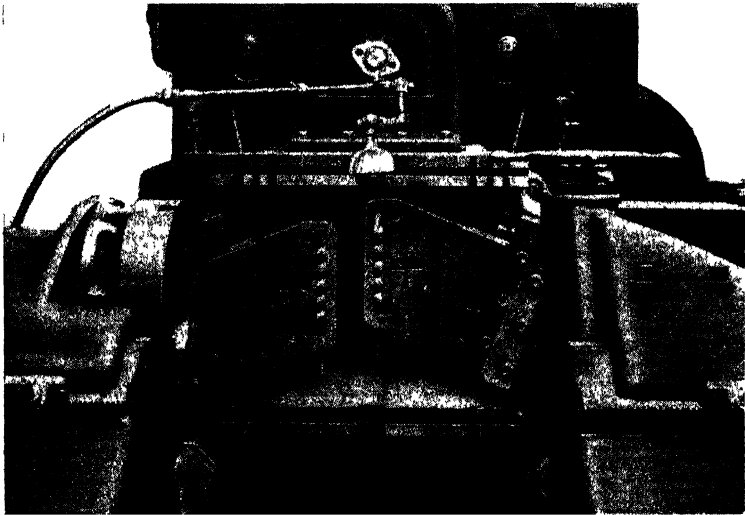


FIG. 29. "SUNDERLAND" DOUBLE HELICAL MACHINE
CUTTER HEAD

To explain the process, the action of the cutters must first be described. The cutters are carried in reciprocating heads which slide in guides inclined at the angle of the teeth, as in Fig. 29. Each cutter is in the form of a rack, and they cut alternately, one cutting towards the centre while the other returns from the centre to the outer end of the stroke. At the end of the stroke the front face of each cutter comes to rest in the central plane. Hence, as the cutters are fed into the work each clears the chip left by the preceding

stroke of the other cutter, and they produce as a result double-helical teeth with sharp apexes.* A "David Brown" machine with a gear in process of cutting is shown in Fig. 30.

In order to obtain the correct involute profile, a generating motion is given to the rack cutters and the blank. This motion is identical in principle and action with that already described in connection with the Sunderland process for spur gears. Hence, one pair of rack cutters will cut any number of teeth of the given pitch. The Sunderland process undoubtedly marked a great step forward in helical gear production when it was first introduced, and is still very widely used. It has a serious competitor, however, in the hobbing process, which is more adapted for the cutting of large, high-speed gears.

The Sykes Process. This process represents the application of the Fellows process for spur gears to double-helical gears, and is applied in a manner analogous to the Sunderland process so far as the production of the apex is concerned.

In the Sykes process the work is acted upon by two circular cutters, similar to Fellows cutters but having helical teeth. These cutters reciprocate to and from the centre, cutting alternately, and are given a helical travel corresponding to the helix angle of their teeth by means of helical guides. There is no indexing motion as there is with the Sunderland process, and gears of exactly similar characteristics to Sunderland gears result.

The Hobbing Process. Single-, double-, and triple-helical gears can be produced by hobbing, and the action of cutting is exactly the same as described under "Spiral Gears." Continuous teeth cannot, however, be produced, and it is necessary to leave a gap between the ends of the teeth of the adjoining spirals. This gap is roughly equal to the pitch.

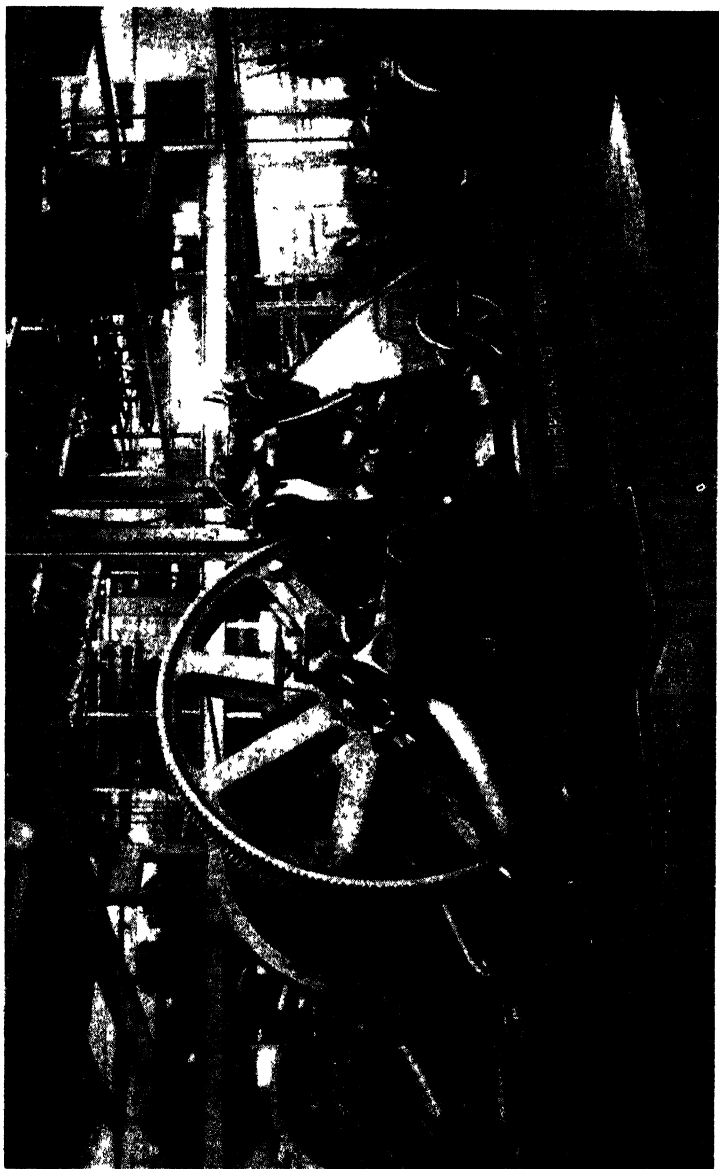


FIG. 30. DOUBLE HELICAL PLANING MACHINE
Sunderland process

Fig. 31 shows a close-up view of the ends of the teeth of a hobbed gear with "staggered teeth," such as are commonly used for gears for heavy duty, e.g. for haul-

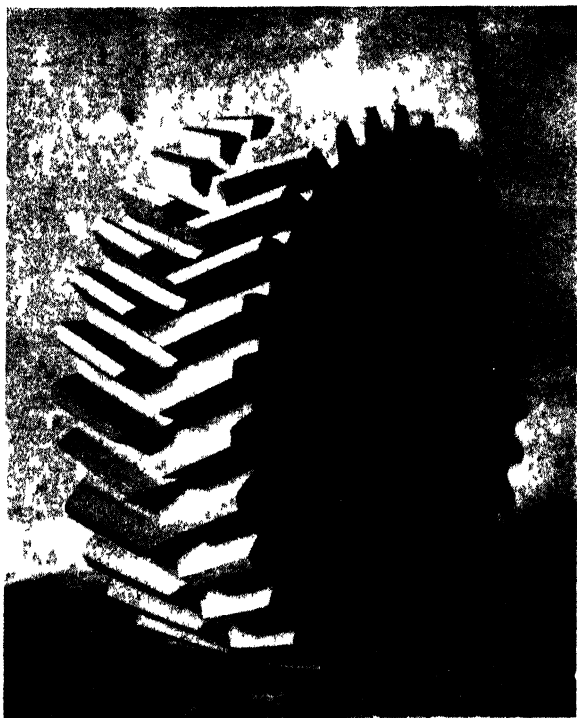


FIG. 31. HOBBED DOUBLE HELICAL GEAR WITH
STAGGERED TEETH

age and winding gears for the mining industry. By "staggered" is meant that the teeth of the two halves of the gear are displaced half a pitch, so that when cutting one side the hob teeth clear themselves in the tooth space of the other side.

Fig. 32 shows a large double-headed hobbing machine designed for the cutting of large high-speed helical

gears such as are used for turbine reduction gearing. Each head carries a hob, whereby the two halves of the face-width can be cut simultaneously when rough-cutting; but finishing is done by one head only.

It is in connection with these large high-speed gears, which have to be extremely accurately cut, that the hobbing process stands supreme. The reasons for this are, firstly, that the action of hobbing involves only continuous rotational motion, which is conducive to accuracy. Secondly, the hob has a very large number of cutting edges, which by an ingenious axial feed of the hob can be successively brought into action as the hob travels across the face of the blank. Hence, every part of the gear is cut under the same conditions.

Comparison of Various Types of Helical Gear. Each of the three types of helical gear finds in general its particular type of application, and they may usefully be briefly compared as follows—

End-milled teeth are used for large gears having coarse pitches and running at slow speed. Errors of manufacture are greater than with generated gearing. These gears, in addition to rolling-mill work, are used for some large winding and haulage gears, but for these last-named applications, hobbled gears are now finding more favour.

Generated teeth (Sunderland process) are used for gears of medium size, where cutters are not too expensive, running at moderate speeds—up to, say, 3000 ft. per min. Besides giving quieter running than spur gears of equal accuracy, they are not unduly costly to manufacture.

Hobbled teeth are used where accuracy is most essential, such as in turbine gearing of the highest speeds (8000 ft. pèr min. is a common speed), and also where machines for generating by the other processes are not available in sufficiently large sizes.

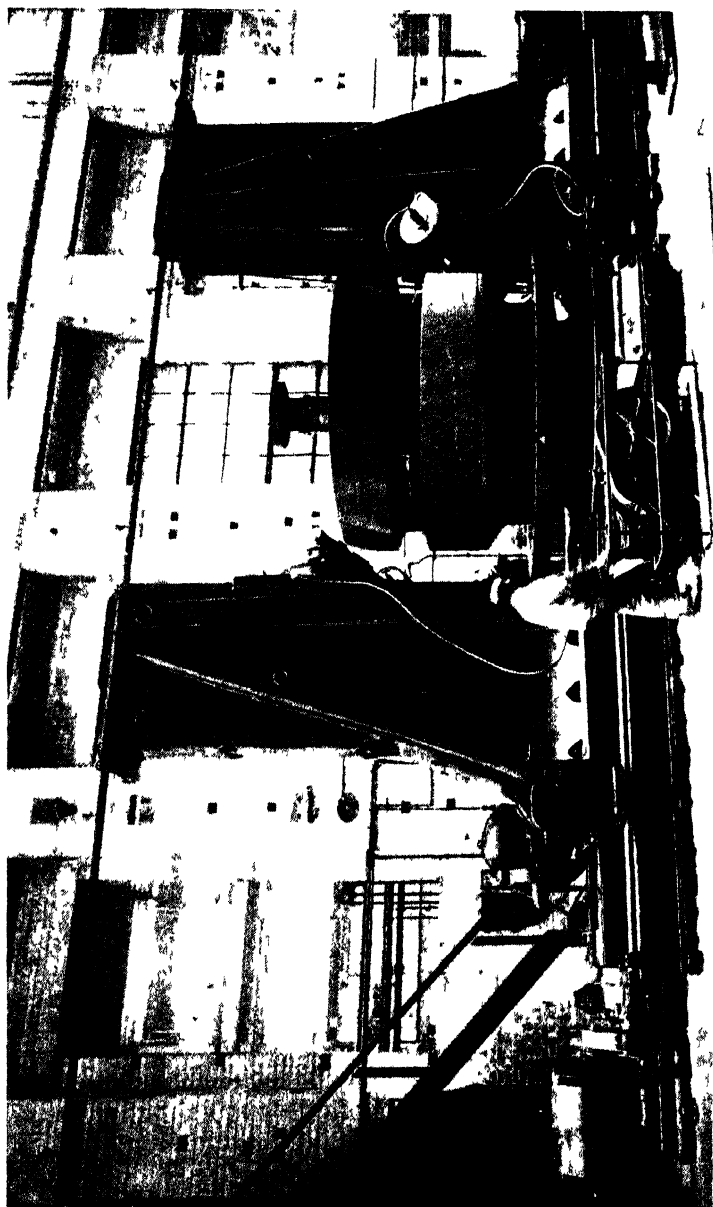


FIG. 32. DOUBLE-HEADED HOBGING MACHINE

WORM GEARING

In appearance and in principle worm gearing is entirely different from other kinds of gearing, and has certain peculiarities and advantages all its own.

The worm is really a screw having helical threads, and differs from the screws used in mechanical construction only in the angle between threads and the axis, and the contour of the teeth. A worm and wheel in mesh correspond closely to an ordinary rack and pinion, the worm being the rack and the wheel the pinion. This is easily understood, when it is considered that if a worm is rotated the threads appear to move along the axis; the effect on the wheel teeth is therefore just the same as if the worm were moved bodily endwise without rotation.

Form of Worm Threads. This analogy between worm gearing and the rack and pinion led to the adoption, by many firms, of the ordinary involute rack tooth form as the basis of the worm thread profile. On the central or axial section, therefore, the worm threads were made straight-sided, with the same proportions for depth as a spur gear tooth, and with a pressure angle of $14\frac{1}{2}$ or 15 degrees, as shown in Fig. 33.

The central section of the wheel teeth, therefore, gives a tooth profile corresponding to an involute spur pinion having the same number of teeth.

Cutting Worm Threads. The method used for cutting the earlier worm threads was to chase them in a lathe with a straight-edged cutter set in the central plane. The principal objection to this method is that it is slow and costly, and therefore when worm gears are manufactured in quantities the threads are milled by rotary cutters in a manner similar to that described for spur gears, with the modification that the worm is

traversed in a helical path. Fig. 34 shows a worm-thread milling machine. The work is carried on a table between centres, and is traversed past a rotating cutter mounted in a head which can be set over at an

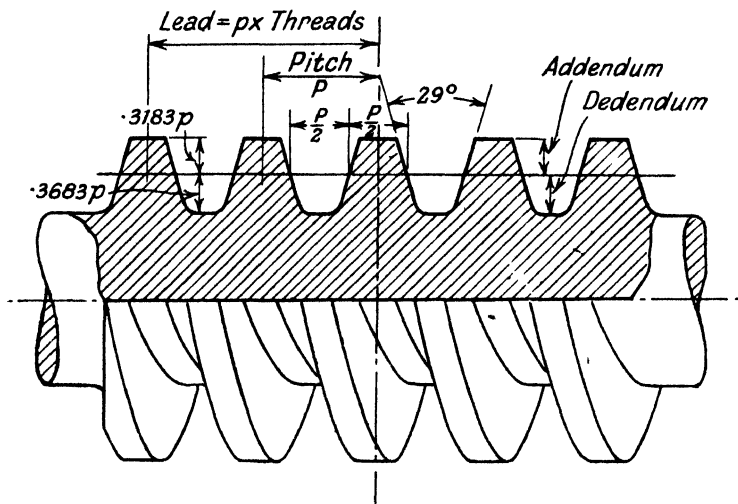


FIG. 33. PROPORTIONS AND NOTATION OF WORM THREADS

inclination corresponding to the angle of the threads to be milled.

The cutter itself is of complicated form. The reason for this is that the "lead angle" of the threads (i.e. the angle which the thread helix makes with a plane at right angles to the worm axis) differs at different points on the profile. Near the root of the thread the lead angle is a maximum, and at the crest it is a minimum, and this leads to a form of "interference" between the cutter and the profile which it produces. Consequently, if the thread is straight-sided the cutter profile is slightly convex.

Hardening and Grinding Worm Threads. The only really satisfactory combination of materials for worm

gearing is a case-hardened worm working with a bronze worm wheel. In the operation of case-hardening, however, a certain amount of distortion occurs, and this distortion must be rectified by a thread-grind-



FIG. 34. WORM MILLING MACHINE

ing process. A further reason for thread grinding is that the finish left by milling is not sufficiently smooth, and would cause wear of the worm wheel; even after grinding, a final polishing operation is necessary.

The operation of thread grinding can be carried out by mounting a portable grinding machine in the tool post of a lathe, but it is more economical in commercial

production to use a specially designed machine for the purpose.

Fig. 35 shows a "David Brown" worm grinding machine. This machine is entirely automatic in operation. After the worm has been placed between the centres and the table mechanism engaged, the worm is automatically finished on every thread. At the

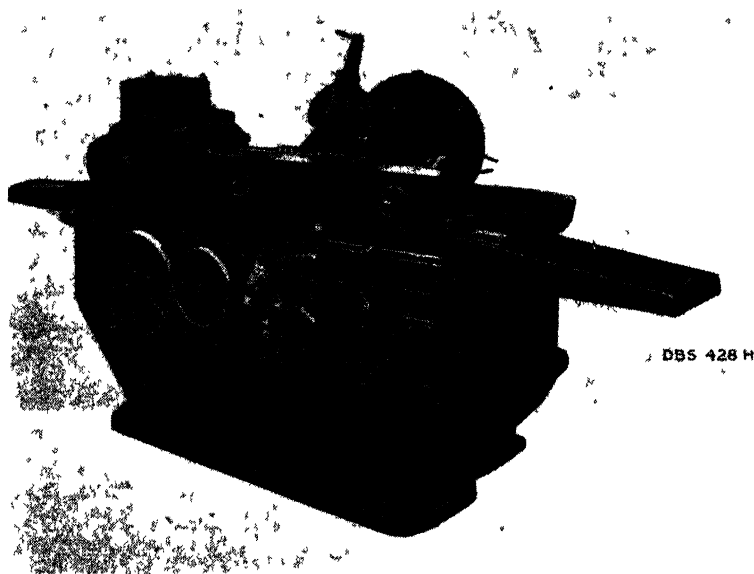


FIG. 35. WORM GRINDING MACHINE

commencement of the cutting stroke the grinding wheel is fed forward to the depth of the thread, and the worm is traversed spirally past the wheel, the lead of the spiral being determined by the change gears of the machine. At the end of the grinding stroke, the direction of the table and the rotation of the worm reverse, and the grinding wheel is withdrawn to clear the threads. During the return stroke, which takes place at a higher speed, the worm is indexed so that in the

next traverse a fresh thread surface is presented for grinding. This process continues until the desired amount of material has been removed, leaving the threads at the correct thickness.

The usual grinding allowance is about seven thousandths per surface, i.e. about fourteen thousandths on

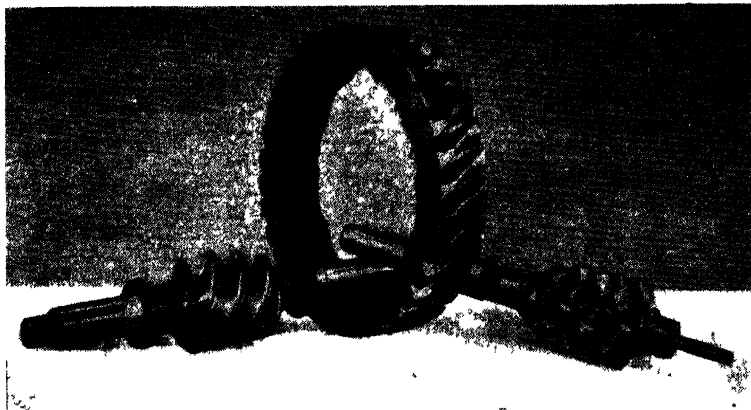


FIG. 36. "D.B.S." WHEEL, WORM, AND HOB

thread thickness. The thickness of the thread is checked by means of tooth calipers, or by special gauging attachments.

Cutting the Teeth of Worm Wheels. Worm wheel teeth must be generated. This is carried out by means of a hob, but, unlike the generation of other kinds of gear, the hob must be of the same form as the worm, and one hob can be used only for one design of worm.

Fig. 36 shows a worm wheel with its worm and the hob used for cutting the teeth.

Tangential Feed. The worm wheel is mounted on a worm-wheel generating machine, and the hob is arranged in a position with respect to the wheel similar to that which the mating worm will ultimately occupy, i.e. in most cases with its axis at right angles

to that of the wheel. By means of suitable gearing the hob and worm wheel are rotated at speeds in the same ratio as those of the wheel and its mating worm, and as the hob is fed into the blank it cuts teeth in the latter. Since the worm threads have a continuous surface, whilst the hob teeth only have cutting edges representing lines or sections of the worm threads, the finish produced consists only of a series of "flats." The size of these flats can be reduced by increasing the number of cutting edges, but there is a limit to which this method can be used. Further improvement is obtained by the use of "tangential feed." This consists of an axial movement of the hob during the cutting operation, so that the position of the cutting edges is constantly changing, but in order to do this the hob must also be given an additional rotary motion. This is similar in principle to the extra rolling motion which is given to a hob through the differential gears, as described in connection with the hobbing of spiral gears. In the case of worm gearing this differential gearing is so arranged that, if the rotation of the table were stopped, advance of the hob would take place with a helical motion corresponding to the lead of the threads, i.e. the hob would be "screwed" through the wheel teeth without cutting or interfering with the teeth already cut. The differential adds this motion to the rotary motions of the table and the hob. Fig. 37 shows a "David Brown" worm-wheel generating machine.

Testing for Backlash and Tooth Bearing. After cutting the gears must be tested for backlash and form of tooth. In order to ensure interchangeability in large batches, both worm and wheel must be kept within certain limits, and this is done by testing each wheel with a "master" worm, and each worm with a master wheel.

In testing, the worm and wheel are mounted in a machine having adjustments for the centre distance, and for the lateral position of the worm wheel with respect to the worm, and the backlash is measured by the rotational movement at the rim of the wheel when the worm is fixed. The tooth bearing is checked by

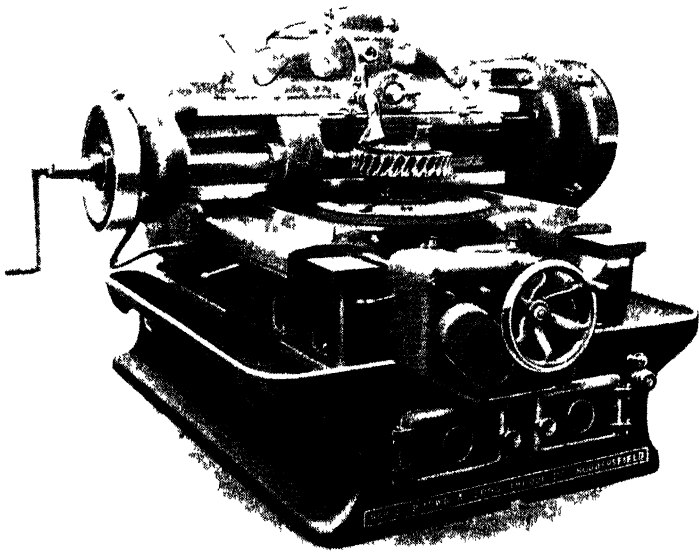


FIG. 37. "DAVID BROWN" WORM-WHEEL GENERATOR

painting the worm threads with a suitable pigment, such as Prussian blue, and then rotating the worm in contact with the wheel, when the pigment is transferred to the wheel teeth where contact occurs. A similar procedure is used when mounting the gears in the machine for which they are intended. Fig. 38 shows a testing machine with a worm and wheel mounted in position for inspection.

BEVEL GEARING

Bevel gears are used to provide a drive between shafts, the centre lines of which intersect; in most cases, the shafts are at right angles. Whereas in the case of spur gearing, the motion is similar to that

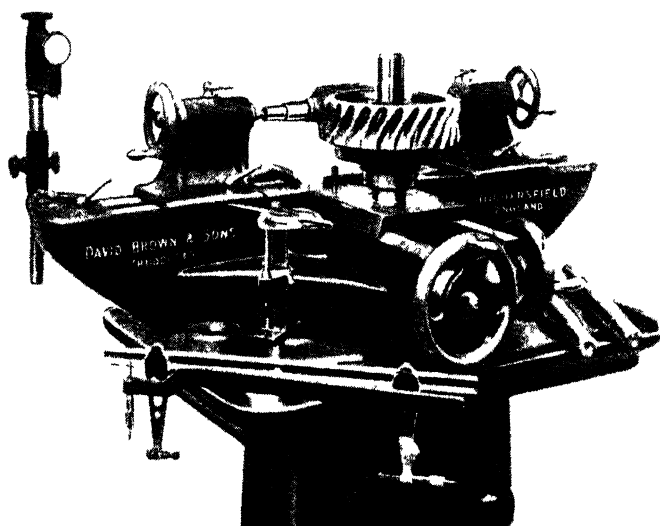


FIG. 38. WORM-GEAR TESTING MACHINE

which would be transmitted by “pitch cylinders” rolling without slip, bevel gears have a relative motion represented by the rolling of two conical surfaces, termed “pitch cones.” These cones have a common apex at the point of intersection of the centre lines of the shaft. This is illustrated in Fig. 39, where OA and OB are the centre lines of the shafts, and OP is a line which sweeps out the rolling conical surfaces. The radii AP and BP are the radii of the pitch circles of

the gears, and the diameters of these pitch circles are related to the gear ratio required in exactly the same way as for spur gears.

Tooth Form of Bevel Gears. If any point be taken on the line OP in Fig. 39, the circles on the two pitch cones passing through this point will have the same

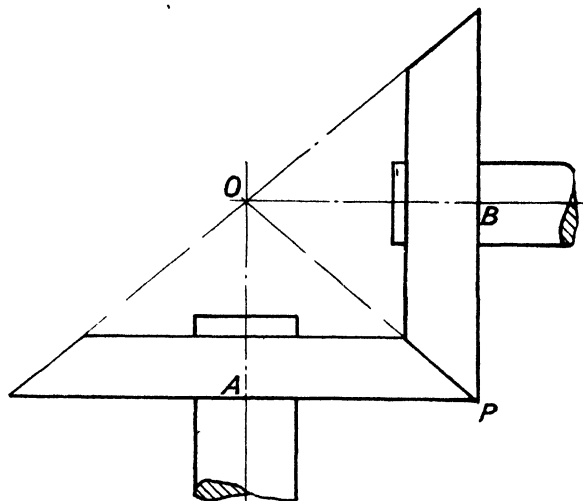


FIG. 39. PITCH CONES OF BEVEL GEARS

ratio, but their actual diameters will be proportional to the distance of the chosen point from O . Hence, the circular pitch of the teeth will be progressively smaller the nearer they approach the apex O .

The tooth profiles are therefore of a constant form, but to a gradually diminishing scale, being largest at the maximum diameter of the gear and diminishing (theoretically) to a point if they were continued to the apex. For this reason it is impossible to cut accurate bevel gears by means of a rotary milling cutter. This method is certainly used at times, the process consisting in mounting the blank on the dividing head of a

milling machine set at the appropriate angle, and cutting the teeth with a rotary cutter of the type used for cutting spur gears. Even though two cuts are taken for each tooth (one for each side), the profile is necessarily incorrect, and the resulting gears are only

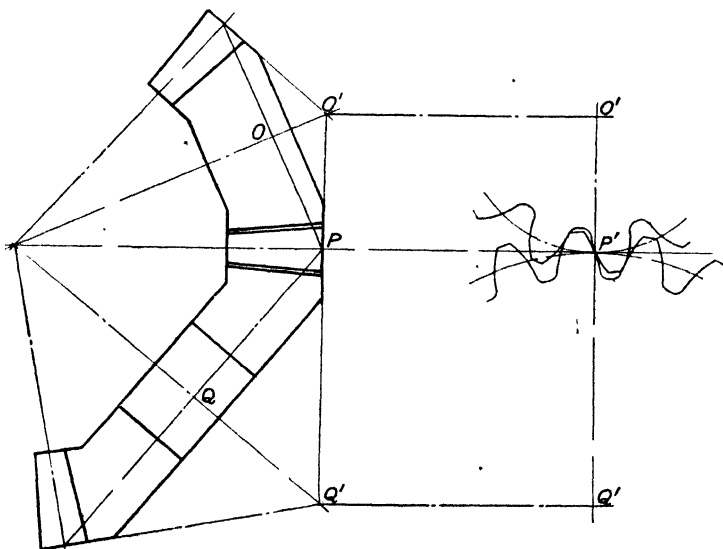


FIG. 40. DETERMINATION OF "VIRTUAL" PITCH CIRCLES

suitable for purposes where accuracy is not required and where the tooth loading and speeds are low.

The profiles of the teeth of bevel gears are quite different from those of spur gears of the same pitch and ratio. The way in which these profiles are derived is shown in Fig. 40. The blanks are turned so that the "back cones" $O'P$ and $Q'P$ are at right angles to the centre lines of the teeth, i.e. the tooth profile as seen by looking on the back cone is approximately a section at right angles to the tooth. If the back cones be developed, i.e. laid out flat, the teeth will be seen to be spaced out round "virtual" pitch circles, the radii of

which are the radii of the back cones. In other words, whereas the teeth of the gear in Fig. 40 are actually spaced round circles of radii OP and QP respectively, the tooth profiles are those of spur gears of radii $O'P$ and $Q'P$ respectively.

Generation of Bevel Gear Teeth. Generation consists in "rolling" the blank over a cutter, the cutting edges of which sweep out surfaces corresponding to the tooth surfaces of a gear with which the blank would mesh.

This can be done for bevel gears in various ways corresponding to the methods used for spur gears. To understand the principle on which these methods are based it is necessary to consider the "imaginary crown wheel," which corresponds to the straight-sided rack of spur gearing. In Fig. 40 the tooth profiles, when the back cones are developed, correspond to spur gears, and between these an imaginary rack with straight-sided teeth could be placed. This rack would be the development of a "crown wheel," i.e. a bevel gear with a flat pitch surface. Such a crown wheel is shown in Fig. 41.

The sides of the teeth of the crown wheel being straight, the whole profile of a tooth could be swept out by a reciprocating tool having a straight line cutting edge. It is then necessary only to arrange the blank in such a way that it is made to "roll" over the surface of the imaginary crown wheel, of which the cutter represents one tooth. During this rolling action one tooth will be generated, and after indexing the process is repeated to finish the entire gear.

The first machine to be built on this principle was the Bilgram machine. In this machine the tool was carried on a reciprocating ram resembling that of a shaping machine, whilst the rolling motion of the blank was obtained by securing a cone to the work spindle, this cone being constrained to roll by means

of steel bands as the head carrying the work spindle is swivelled round a vertical axis. Fig. 42 shows a group of straight-toothed bevels produced on this principle.

Machines using the same principle but employing two reciprocating cutters, finishing both sides of a tooth at once, are built by the Gleason Co., and an example

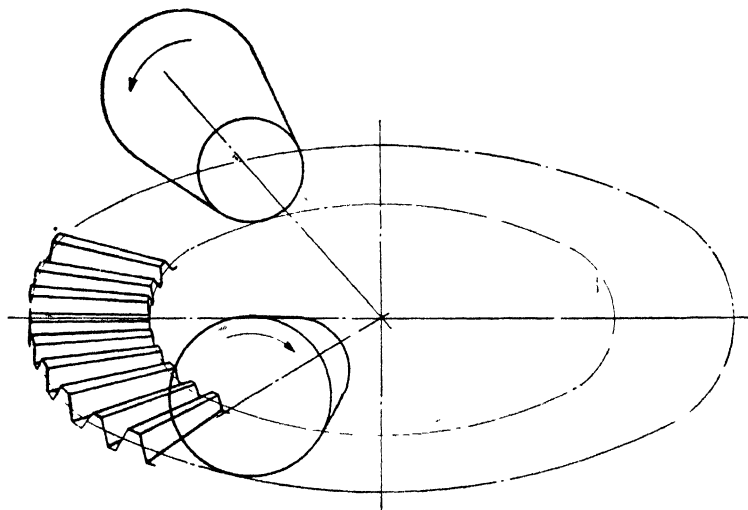


FIG. 41. ROLLING OF BEVEL PINION WITH CROWN WHEEL

of a machine of this kind is shown in the foreground of Fig. 43. In this type of machine the blank has a rotary motion on a fixed axis and the reciprocating cutters are carried in a cradle (representing the imaginary crown wheel), which rotates in geared relation to the blank to give the necessary relative rolling action.

Straight-toothed bevel gears generated in this way are analogous to spur gears generated from a Sunderland rack cutter. There is, however, no commercial process for producing this type of gear analogous to the Fellows process.

Very large bevel gears, such as those seen in the

background of Fig. 43, would require too large and too costly a machine of the generating type, and consequently they are produced by a forming process. The tool used has a single point, and is carried on a reciprocating slide in such a way that whatever the inclination of the slide the line of action of the cutter always

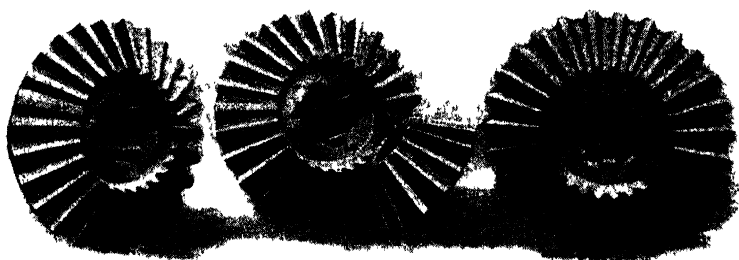


FIG. 42. STRAIGHT-TOOTHED BEVEL GEARS

passes through the apex of the gear. At the outer end of the slide is arranged a former, having a profile corresponding to that of the gear tooth to be cut. A roller on the slide rolls over the former, and thus causes the tool to trace out a copy of the former profile. The profile is therefore reproduced on the gear being cut.

Undercutting in Bevel Gears. Undercutting may occur with bevel gears in the same way as with spur gears, and may be corrected or avoided by the same methods. It is merely necessary to regard the tooth profiles of the bevel gears as corresponding to those of the virtual spur gears.

Gauging Bevel Gear Teeth. The methods employed to verify the accuracy of profile of bevel gears correspond to those used for spur gearing, but are fewer in number. For ordinary workshop purposes the thickness of the teeth is determined by gear tooth calipers,

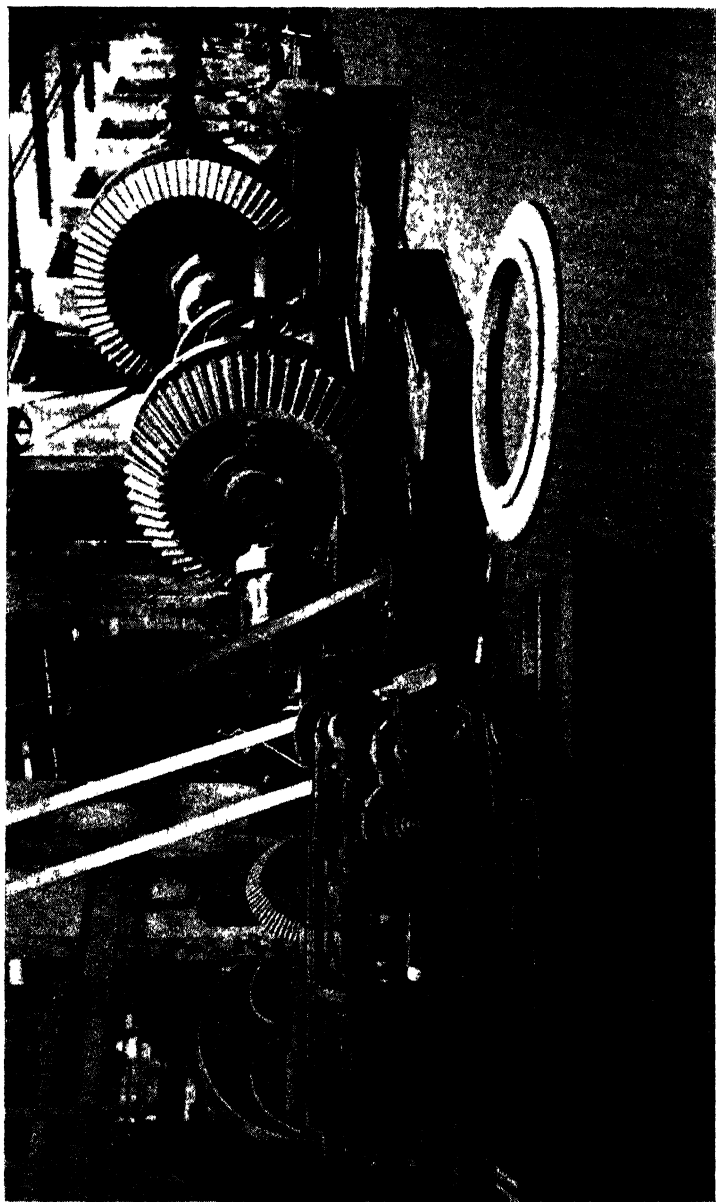


FIG. 43. GLEASON BEVEL GEAR MACHINES

the settings being calculated for the circular pitch on the pitch diameter. The calipers can be applied only on the back cone.

General accuracy of cutting is tested by mounting the gears which are to mesh on spindles accurately set. By painting the teeth of one gear with red lead or Prussian blue and rotating the gears together, the extent of the contact between the teeth can readily be seen. In a refinement of the method, one of the spindles is free to float in a slide and the teeth of the gears are held in mesh by a spring or weight. As the gears are rotated any variation in tooth thickness or tooth profile causes a displacement of the movable spindle, and the amount of this movement can be read on a dial indicated or recorded graphically.

Bevel gears intended to run at high speeds are, in addition, run together under load at speed in a special machine, in order to verify the correctness of the tooth bearing and quietness of operation.

Spiral Bevel Gears. Just as spur gears can be modified to helical gears by forming the teeth at an angle to the axis, so can bevel gears be made with spiral teeth.

The first form of helical bevel gear to be produced by a generating process is what is known as the "single-helical bevel," shown in Fig. 44. The only modification lies in the position of the line of travel of the cutter, which is offset from the apex.

Gleason spiral bevel gears are produced by means of large diameter cutters having a rotary motion. The process is a generating one, the cutters, which are mounted round the periphery of a circular body, having straight cutting edges. The tooth spirals produced are consequently circular arcs (or very nearly so), and a typical pair of gears as used for motor-car rear axles is shown in Fig. 45.

Fig. 46 shows a large Gleason machine. The cutter is clearly seen in the illustration; it is carried on a cradle which represents the imaginary crown wheel and

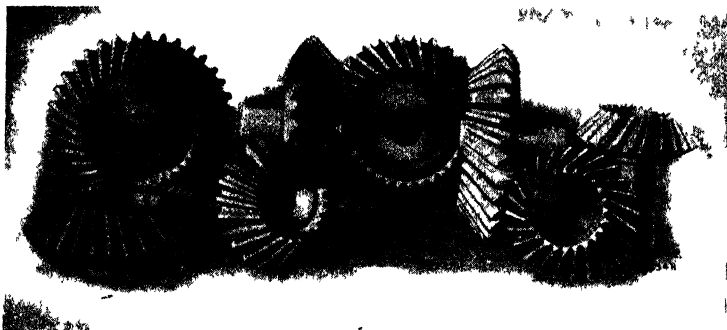


FIG. 44 GROUP OF SINGLE HELICAL BEVEL GEARS

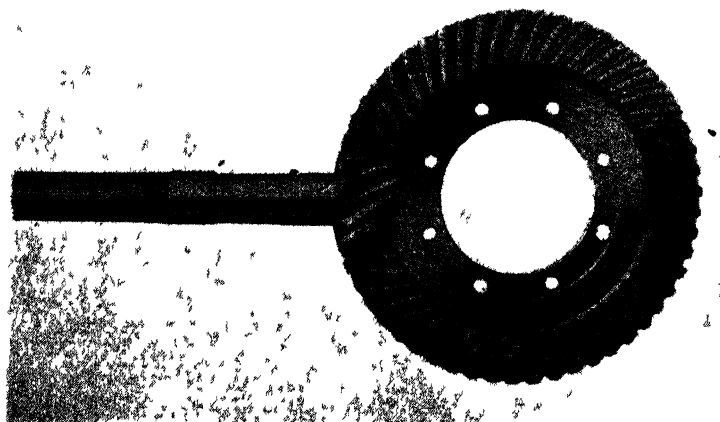


FIG. 45. GLEASON SPIRAL BEVEL GEARS

rotates in unison with the blank. Gleason gears are to be preferred to single-helical bevel gears for several reasons: they are more accurate, have stronger teeth, and have more latitude in mounting.

It is also possible to produce spiral bevel gears by a hobbing process. The hob is of conical form, and has teeth of straight-sided profile and usually of constant

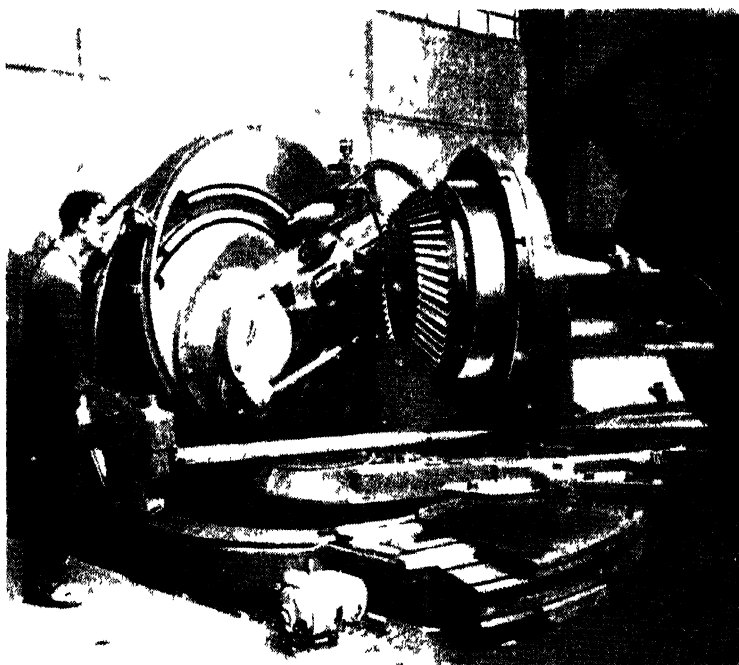


FIG 46 GLEASON SPIRAL BEVEL GEAR MACHINE

pitch. The hob is set obliquely across the face of the imaginary crown wheel, and the blank has a combined rotary motion in unison with the hob, and an additional rotation to compensate for the rolling action. Both the tooth profile and the tooth spiral are then, approximately, involutes of circles, and the teeth are of nearly constant normal pitch and of constant depth.

SECTION XXVII

PLATE SHOP PRACTICE

BY

FRED GUDGEON

Works Manager, International Combustion, Limited, Derby

SECTION XXVII

PLATE SHOP PRACTICE

PLATE SHOP WORK

PLATE shop work is nowadays such a wide term that before attempting to give any detailed information it would be as well to try and delineate the various trades and types of manufacture which come under it by using plates and rolled sections as their raw material.

The range varies from light metal work in non-ferrous and steel sheet such as ornamental work and domestic utensils to heavy fabrication such as a battleship or tank. In between there are a vast number of different kinds of manufacture all called plate work but each requiring particular methods and tools suitable for that type of manufacture.

Equally the tradesmen are all called platers and sheet metal workers, but to ask a man who is used to working light sheet, say, in the Birmingham district to go and work as a plater in a shipyard would be like asking a navy to go and work as a coal-miner because he can use a pick. The methods differ so much owing to the difference in weight of raw material that such a change becomes almost a change of trade.

Bearing this point in mind, this survey of plate work must be in general terms rather than in detail for any particular section. We shall, accordingly, deal mainly with the medium weight as being the most common type of manufacture and most applicable to the majority of people interested in plate work. The term plater relates to work in metal varying from about

0.022 in. thick used by the tinsmith or metal spinner to heavy plate inches thick used in ship work. In between there are sheet metal workers who usually work in plate up to about $\frac{1}{16}$ in. thick.

A few preliminary notes on the method of manufacture of the plater's raw material might be an

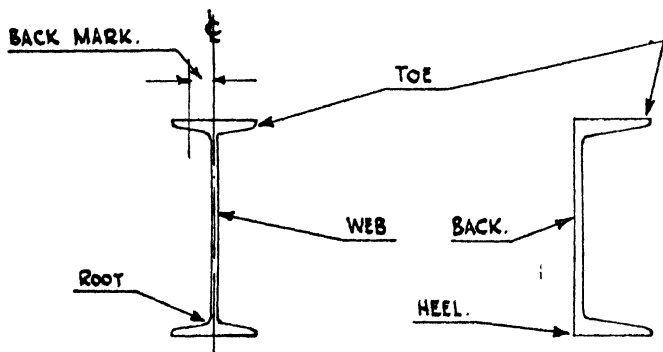


FIG. 1. STANDARD ROLLED STEEL SECTIONS

advantage as so much depends on the finished product from the rolling mill to give a satisfactory result after manipulation in the plate shop. The material is supplied to the mills in the form of ingots, billets, slabs or bars and must be passed backwards and forwards between rolls until the desired thickness and shape has been obtained. Some metals can be rolled cold whilst the harder ones must first be heated to enable the pressure applied by the rolls to deform them to the desired shape.

Briefly, a rolling mill consists of one or more pairs of rolls mechanically driven, through which the material is passed a sufficient number of times to reduce it to the desired shape. Usually a mill consists of two or three pairs of rolls, one above the other, and the material is first passed through the lower pair for roughing out, then by means of a rising platform is

lifted and returned through the pairs of rolls above for the second or finishing pass.

For shapes and sections the rolls are grooved in stages so that at each pass the metal is advanced a stage at a time towards its final shape. Usually it requires at least three passes to obtain this.

With the softer metals it is possible also to draw them through dies to give a desired shape, and a much greater variety of shapes can be obtained in this way.

The condition of the metal when it comes from the rolls is of primary importance to the plater who has to work it, i.e. bend it, roll it, or cut it during fabrication. In the old days of wrought iron, owing to the impossibility of avoiding the inclusion of slag and other impurities from the billet, the rolling operation produced a series of laminations or fibrous structure in the sheets which made it necessary to use very great care when bending the plate to prevent cracks developing along the slag line, and usually it was necessary to bend the plate transversely across the laminated structure to avoid such cracking.

Nowadays the control in the melting ensures a much purer metal and the modern mild steel plate can be worked in any direction without fear. At the same time when a plate is being rolled it is often passed through the rolls first across the width and then down the length of the billet to reduce any tendency towards this laminated structure.

With regard to quality, there is now such a wide choice of plates of varying physical properties that it is possible to obtain a plate suitable for any particular performance, such as high ductility for pressing or high tensile where strength and lightness are important or toughness for armour plate. That is to say, it is not necessary to add weight to gain strength, because there is a steel available which can be used to give the

necessary qualities without adding to the weight. Standard specifications have been issued giving all the physical properties of the different metals and it is now only necessary to decide, with the aid of the makers, the most suitable specification before commencing to work.

METHODS OF FABRICATION

The principal operation in the plate shop is that of joining plates and sections together to form a complete assembly. There are various methods of doing this and it is necessary in the design stages to consider which is most suitable for the particular condition.

Joints can be made by bolting, riveting, and welding—in its various forms—for heavy plates, and for lighter plates there is also spot welding, fusion welding, brazing, soldering and folded seams. The main points to consider are that the joint shall be of ample strength and rigidity to fulfil its required duty under the working conditions which the apparatus has to withstand, and also the cost of material and the time required to make the joint.

TYPES OF JOINT

The bolted joint is the most common and probably the cheapest method, the bolt holes usually being drilled $\frac{1}{8}$ in. larger in diameter than the bolt for ordinary black bolt work, that is, work not demanding any very great accuracy or carrying heavy loads. Where finer limits must be worked to, the bolt hole is usually $\frac{1}{16}$ in. larger than the bolt; this is called a finished black bolt joint.

If a still greater limit of accuracy is required or where it is a main joint in shear, such as the main girders of a bridge or heavy supporting structure, then a fitted bolt is used. This requires the steelwork to be erected in

position and when finally lined up the bolt hole is reamed out and a special bolt is made exactly to fit the hole. This, of course, is an expensive joint because it very often necessitates scaffolding being specially rigged up to give access for the men.

The allowance of $\frac{1}{8}$ in. for black bolts may appear unduly large, leading to a loose joint, but it must be remembered that when dealing with rolled sections a tolerance has to be allowed for variation in thickness of the sections. It is not possible to roll any section to the exact drawing dimensions because the rolls wear and consequently the sections come out thicker than the drawing size. The rolling mills, therefore, only guarantee to supply sections to within a certain limit of accuracy. Usually it is up to $\frac{1}{8}$ in. max., and is called the rolling tolerance.

It will be seen, therefore, that when assembling steel parts together some will be slightly larger and some slightly smaller than the drawing; consequently unless all the steel is assembled together by means of clamps and the bolt holes drilled in position, it is not possible exactly to mark off all the holes and to find them register exactly on being offered together.

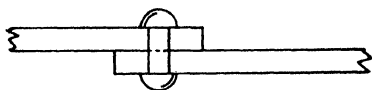
In making a bolted joint on to rolled steel sections, a special taper washer has to be used to make up for the slope on the inside of the section, so that the nut is tightened down on to a face square with the shank of the bolt, otherwise the bolt will be bent and probably break.

RIVETED JOINTS

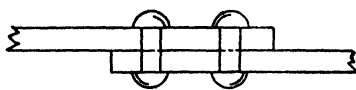
This type of joint is the most popular where rigidity and strength are required, and there are various combinations of joint depending on the duty the apparatus has to perform. Two of the more common ones are shown in the top half of Fig. 2. The plates

are either drilled or punched, the position of the holes being marked off to a templet or directly on to the material.

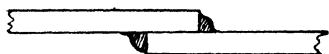
The important points to watch in riveting are that the



SINGLE RIVETED LAP JOINT



DOUBLE RIVETED LAP JOINT



WELDED LAP JOINT.



WELDED BUTT JOINT.

FIG. 2

shank of the rivet entirely fills the hole when driven home, that the point is formed the correct shape with the riveting snap, and centrally round the centre line of the rivet, and also that the holes through the plates register and are not stepped, otherwise the rivet shank does not fill the holes completely.

An inspector when inspecting rivets usually tries to insert a feeler under the head of the rivet to see whether the rivet head has been thoroughly hammered down so that the various layers of material are pulled absolutely tight when the rivet cools.

It is important, therefore, to see that the correct length of rivet is used, otherwise if too long it will not be possible to form the rivet point properly owing to there being too much material to hammer down, and if too short, a full point cannot be made because of lack of material.

Fig. 3 illustrates the result of the rivet holes not registering correctly and the consequent distortion of

the shank of the rivet. Fig. 4 shows the result of not having the two plates forming the joint tightly bolted up, leading to the rivet swelling out and permanently forcing the plates apart. Fig. 5 shows the result of

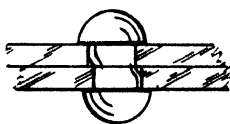


FIG. 3

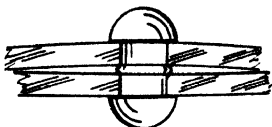


FIG. 4



FIG. 5

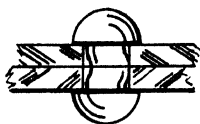


FIG. 6

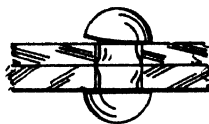


FIG. 7

either too long a rivet or the rivet snap being too shallow, causing the excess metal to be forced out round the edges. Fig. 6 is the result of a rivet either being insufficiently heated or not being the correct size. The same remarks apply to Fig. 7 where, in addition, the riveter or holder-up has not applied equal pressure all round the rivet head, with the result that one side was down and cooled before the other side could be finished off.

There are various additional expedients used in riveted joints when high pressure has to be dealt with. For instance, sometimes rubber, brown paper, red lead, or leather is put in between the plates to form a plastic jointing material which fills in any cavity or unevenness in the face of the plate. This saves the necessity of machining the plate and makes it quite a satisfactory job. At the same time where really high pressures have to be contended with it is necessary to machine the two faces to be joined together to ensure a perfect metal to metal joint.

RIVETING

Riveting as a method of securing two or more parts together is about the oldest type of joint there is, and except for the adoption of more efficient methods of heating and knocking down the point, the principle and application have not changed.

Whereas hand hammers were used originally, most of the work is now done by power-driven tools unless the amount of riveting is very small, or is in such a position to render the cost of supplying the power prohibitive.

A rivet secures a joint by two means, firstly by the hammering down of the point of the rivet which squeezes the layers of material together and holds them down by the flange of the rivet head, and secondly as a result of the contraction of the shank of the rivet as it cools drawing the pieces tighter together.

Fig. 8 shows the various types of rivet head and a typical riveting snap used in power riveting hammers for knocking the point of the rivet down, also a tool known as a rivet buster for cutting off rivet heads to allow removal.

A riveting squad usually consists of three men, the riveter, the holder-up, and the rivet boy for heating and passing forward the rivet. A fourth is sometimes used to go ahead of the riveters, taking out tacking bolts and faring up the holes. Other tools used are hand tools, consisting of the various-shaped snaps, hand hammers and dollies for holding-up purposes.

Power supply can either be compressed air, hydraulic or electric, the most popular being the hydraulic or the compressed air. Electric tools are coming forward especially for lighter work because of the cheapness of the power supply compared with the other two means, and also because of lighter maintenance due to not having to maintain piping and compressors.

These electric tools are mostly of high cycle low voltage design, which removes risk of injury should the operator come in contact with a bare portion of the



Rivet Set



Rivet Buster

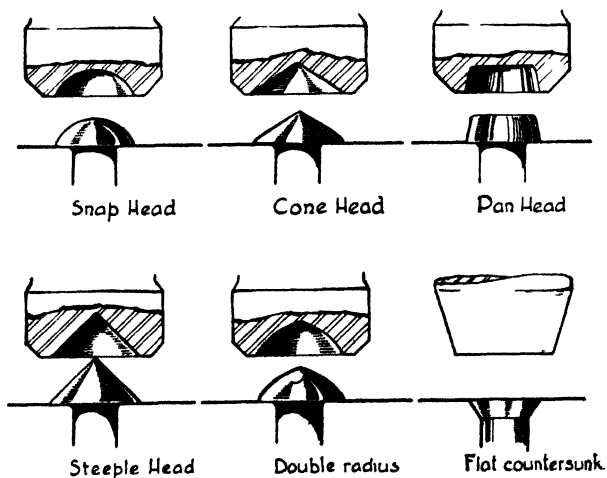


FIG. 8

conductor, in the event of the cable being cut. For heavy riveting work the hydraulic riveters are more popular.

Fig. 9 is a section through a typical pneumatic riveting hammer for medium-sized work operating

with an air pressure of between 80 and 100 lb. per square inch.

Air is admitted through the pistol grip handle (1), and is controlled by means of a lever operated throttle valve (7) of the piston and poppet type. The air passes from this valve to the oscillating piston valve (4), which moves in a valve box (2) and (3).

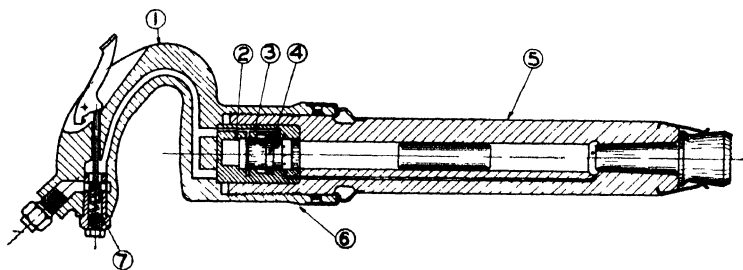


FIG. 9

As will be seen, air ports in the valve box admit air which is controlled by the piston valve as it oscillates up and down inside the box, thus cutting off and releasing air which passes through the lower port to the bottom end of the barrel (5). Situated in the barrel is a loose piston which is forced up and down the barrel by means of the intermittent air supply, at each cycle striking the end of the riveting snap and producing a hammer blow at a very high frequency. The exhaust air is then released through the ports in the outer portion of the handle, which are protected by a spring (6), which also acts as a lock to prevent the handle working loose.

The riveting snap is inserted in the end and held by means of the spring clip, but can be easily withdrawn so that any type of snap can be inserted according to the shape of the head desired.

The heating of rivets is an important operation, and unless correctly done can seriously weaken the joint

or make it impossible for the riveter to make a satisfactorily shaped point.

There are various ways of carrying this out, either over an ordinary coke fire or by muffles heated by oil, gas, or electricity. In addition, they can be electrically heated by means of a resistance heater, which consists of two heavy copper electrodes, between which the rivet is inserted and a heavy current passed through sufficient to heat up the rivet to the necessary red heat.

This is a very satisfactory method, because of the even heating through the mass compared with the possibility of only the outer portion being heated by the other methods. Equally, a rivet can be overheated and burnt very easily and so ruin the properties of the material.

WELDED JOINTS

The advance in welding technique has resulted in this method replacing bolted and riveted joints to a very large extent. It is not possible to lay down any rule for deciding when a riveted or welded joint should be used because so much depends on the working conditions and the facilities of the manufacturer. Much argument prevails between the two schools of thought as to whether welding or riveting is the better, and it is probable that the answer is that they are both equally good, depending on the particular conditions.

The advantage of welding is that a saving of weight can be made up to 20 per cent owing to the ability to dispense with the butt straps, cleats and stiffening which are necessary in riveted or bolted joints, and also the weight of the bolts and nuts, so that on a large contract considerable saving may be obtained by adopting welded construction.

As a comparison it can be said that the cost of a welded or riveted structure is approximately the same,

because the material still has to be marked out, and whilst there are no holes to be drilled for welded structure, it has to be tacked up and a certain number of fixtures and jigs made which are not required on the riveted type, so that generally speaking the saving between the two is largely the amount of weight which can be cut out.

It is not possible to go into the various methods of welding very deeply here, but it can be said that recent research work has developed very high technique and it has become a skilled craft demanding considerable experience if the various types of welding, especially of the various alloys now on the market, have to be dealt with.

The most common method of jointing plate work is the lap and the butt weld (see Fig. 2). There are others for special positions.

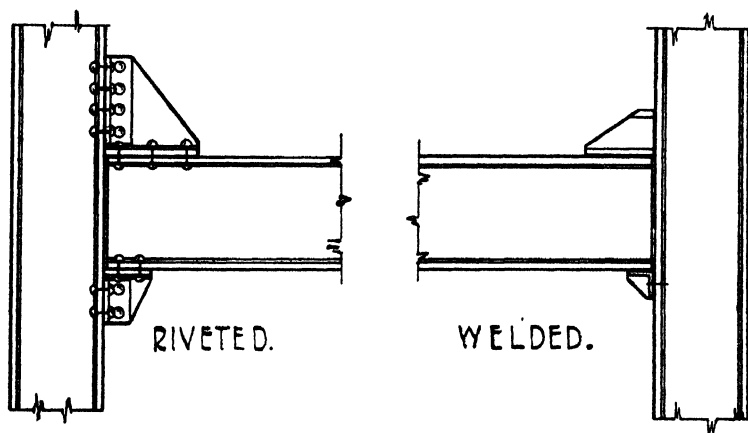
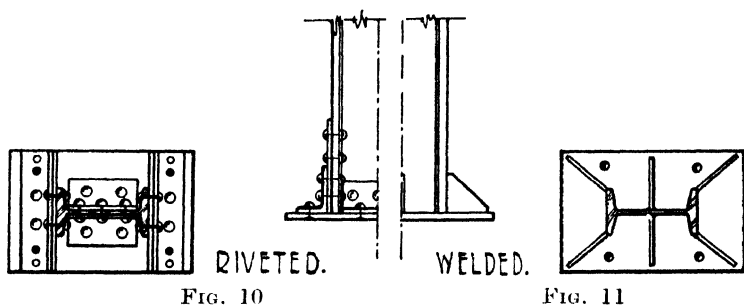
The lap joint is the easiest because it requires the least preparation and is the most simple to weld because the plates form a natural Vee and no very great skill is required to deposit the weld metal satisfactorily.

On the butt type of joint more skill is required to obtain an even deposit of metal to get a thorough penetration at the bottom of the Vee without excess metal protruding, but it is, of course, necessary to prepare the edges by bevelling to form the Vee, although for less important joints the plates are left square edged and the weld metal is deposited across the joint. Butt welding is more successful with the thicker plates and usually is not used on thicknesses under $\frac{3}{16}$ in., except for specialized work.

Vessels are now successfully constructed by welding to withstand very high pressures equally as well as riveted vessels, except that it is not yet known what the effect of time will have on the welded joint owing to ageing and reversal of stresses, as the welding method

has not been in use a sufficient number of years to enable such a comparison to be made.

Figs. 10 and 11 are typical arrangements of a stanchion base using the riveted and welded construction. It will



be seen that on the welded design considerably less work has been entailed and also riveting and angle plates dispensed with.

Figs. 12 and 13 show a riveted and welded joist connection where once again the amount of material is considerably reduced on the welded design compared

with the riveted, but it is important that when deciding which of the two methods of construction is to be adopted, the welded design should be carefully considered by practical welding engineers so that the strength is put in the right place.

Generally speaking, it is not easy for a draughtsman brought up to riveted design conditions to design a corresponding welded construction. It has been found that it is better to train a draughtsman without any preconceived ideas for welded work, because there are so many radical differences in the application of welded design, not so much from the stress point of view as from that of application of the stiffening and supports. A draughtsman brought up to riveted design is inclined to overload a welded design and so nullify the advantages obtained by the savings which could be made in weight.

The most commonly used method of welding is the electric arc, either A.C. or D.C. followed by oxy-acetylene, carbon arc, fusion welding, gas welding, Union-melt, atomic hydrogen and various others for special purposes. They all have specific advantages either for speed, quality of weld, or special alloy.

WELDING

Apart from the application of welding to straightforward structural and plate work, very great strides have been made in the substitution of welding for castings. Parts varying from 1 lb. to tons are now made in fabricated steel which were previously made in the foundry, necessitating patterns and all the necessary foundry work.

On the Continent and in America appreciation of the possibilities of welded fabrication was quicker than in this country, but advance is now rapid here and a great deal of leeway has been made up. Designers

are now specializing in welded fabrication to a very considerable extent, and structures are being accepted to-day which would scarcely have been considered a few years ago.

Even now, however, we are still slow in following the Continental application in making special sections

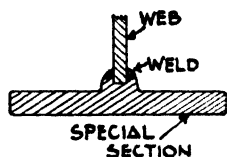


FIG. 14

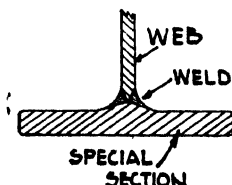


FIG. 15

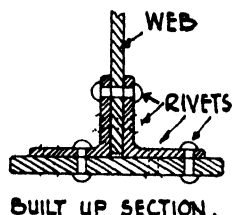


FIG. 16

designed exclusively for welded construction. Special sections are now made, some of which are shown in Figs. 14 and 15, designed expressly to enable welded technique to be applied correctly and to reduce the number of pieces in a section.

It will be observed from Figs. 14 and 15 that the number of pieces required to build up a welded girder, using the special sections, compared with one using the standard British rolled sections, Fig. 16, offers opportunity for reduction in weight without any reduction in strength, because the redundant material required to provide for riveting is not needed when the special welded sections are used. It will be seen that by this method much less welding is actually required, and the position of the weld being mostly downhand offers much less difficulty and consequently enables less expert welders to be employed.

Bridges constructed solely of welded parts are becoming very popular abroad, and although there have admittedly been one or two cases of failure they have on the whole been very successful and offer

probably more opportunity from the artistic point of view than riveted structures of the same type. It may be that owing to these failures a certain amount of reluctance to adopt welded design has been noticeable in this country.

In ship construction also welding is steadily advancing, and quite a large number of ships have been constructed wholly by welding methods, including some naval ships, whilst where the hull is riveted a considerable amount of the internal structure and bulk heads has been of welded design.

There are a number of automatic machines on the market for making continuous welds. using a variety of methods, such as carbon arc, the electric arc, atomic hydrogen and others, and a large number of special purpose machines for making a particular item exclusively.

A typical continuous welding machine is shown in Fig. 17. This is for continuous welding of seams of tanks or vessels, or any work of that nature, and as will be seen consists of one or more travelling welding heads designed to travel along a fixed bed, the electrode traversing the joint to be made.

On the welding head a coil of electrode wire is carried in a drum and by means of a small motor the electrode is continuously fed to the arc and the feed is synchronous to give the exact amount of wire to suit any speed of traverse of the welding head, this of course varying with the thickness of the joint. Speeds from 8 in. to 30 in. a minute can be obtained.

Plates varying in thickness from small gauge plate to heavy boiler drums are now welded by one or other of these automatic methods, and electrodes up to $\frac{1}{2}$ in. diameter are being used. In the latter case the rod, of course, is too heavy to be carried in coils, but is supplied in lengths of about 3 or 4 feet, one end being

drilled and tapped whilst the other end is screwed externally.

As the rod is fed towards the arc the operator screws a further rod into the tapped hole of the previous one, thus obtaining a continuous electrode.

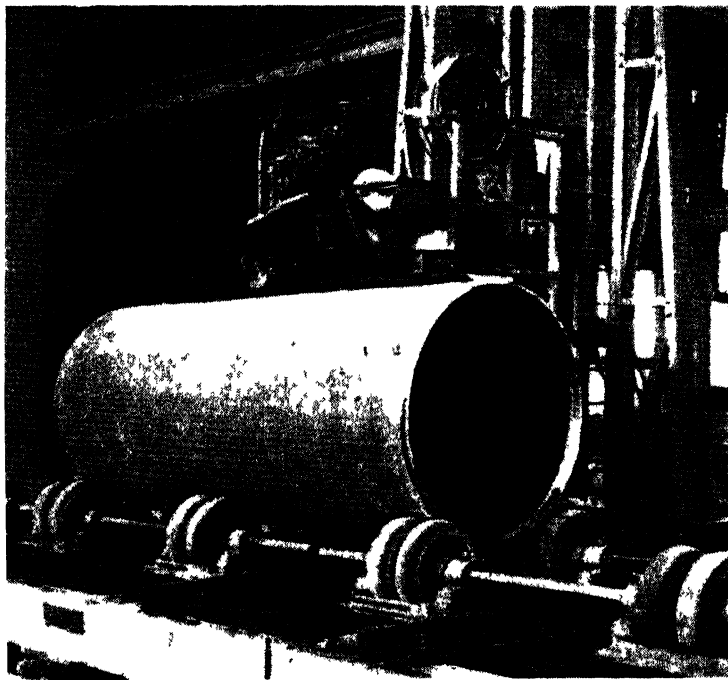


FIG. 17

The atomic hydrogen method is also finding increasing popularity, especially for light work.

This method uses the electric arc principle, with the difference that instead of using a coated electrode to provide the necessary protection against oxidization whilst the metal is fluid, a jet of hydrogen is directed through a circular nozzle surrounding the electrode,

which completely shrouds the arc in an envelope of hydrogen, thus preventing any access of oxygen to the weld. By this method excellent joints are made free from gas holes and having a very smooth and regular contour. In addition, of course, there is no slag to be brushed off as when using a coated electrode.

A further difference between the atomic hydrogen and the electric arc method is that the arc is struck between a tungsten electrode and the work, and the action due to intense heat is rather to melt the parent metal and fuse the two sides of the joint together, than to apply additional metal from the electrode. A filler rod is used by the operator whenever there appears to be a deficiency of molten metal from the parent metals; this filler rod is inserted into the arc to provide additional metal. In this respect it can be said that the atomic hydrogen weld is a cross between electric arc welding and gas welding.

Oxy-acetylene is, of course, still used very considerably, but is being replaced to some extent by one or other of the electrical methods. It has still, of course, a field of its own, being used almost exclusively for welding non-ferrous metals, and also for high pressure work, particularly site work where transport of gear becomes important and where there may not be an electric supply suitable for any of the electrical methods.

Another very important advantage of gas welding is that where the work must be capable of withstanding pressure, it is necessary to anneal the joint after the weld is finished so as to relieve welding stresses and remove any brittleness. This annealing can be easily done by means of the blow pipe so long as care is taken that the work is shielded from cold winds, which would produce unequal and too rapid cooling and thereby re-create the stresses which annealing has been used to remove.

A further very rapidly increasing field for welding is in repair work. This has developed enormously and proved highly successful. It, however, calls for considerable ingenuity and welding technique of the highest, because varying types of metal have to be repaired necessitating special welding technique as well as special rods, which must be suitable for the particular grade of the original casting. Here, again, both gas and electric methods are used, dependent on the material of the broken part.

Some very remarkable repairs have been effected by this method and a large amount of money and time saved which would have been incurred had new castings been obtained. Fig. 18 shows a hydraulic cylinder weighing 21 tons which had broken in two pieces and which was repaired by welding and back in service in four weeks from the breakdown. To obtain a new steel casting and machine would have taken at least ten weeks.

Equally, repair of small parts can be just as successful, and as practically any metal can be welded to-day there are few breakdowns which cannot be overcome, even if only temporarily, by the aid of the welder.

It is not the intention in this section of the book to go into the technique of welding, but only to show how welding in the plate shop has developed over the last twenty years, and to give some idea of the scope offered to the plate shop in its application.

SPOT OR RESISTANCE WELDING

This method consists of introducing the articles to be joined together between two electrodes through which a high current is passed, sufficient to make the metal red hot and thus render it plastic. Whilst this current is being passed through, a pressure is applied which forges the two parts together in just the same way as any forging on the anvil.

Machines are constructed so that the exact pressure and current is applied and automatically cut off as soon as the joint has been made. They are designed so

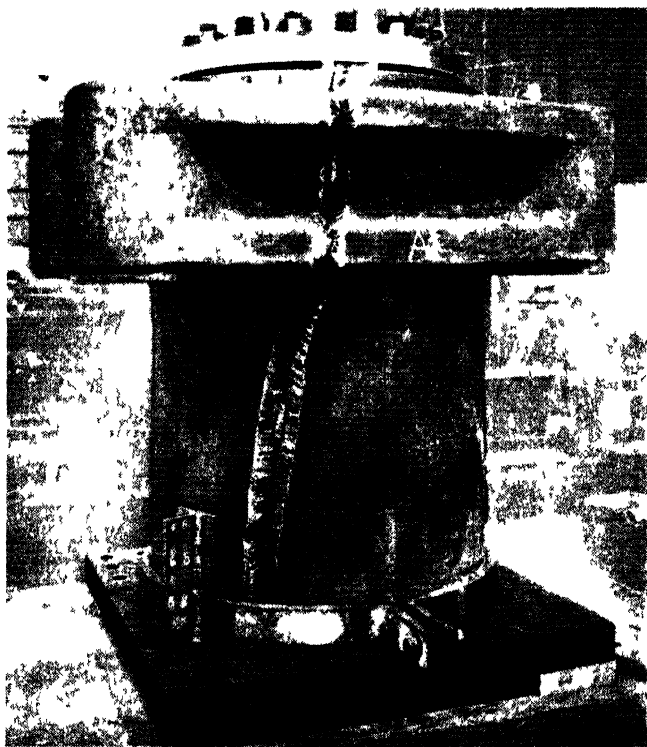


FIG. 18

that either a series of spots at intervals can be made, or the spots are so rapid that one overlaps the other; this is known as stitch welding. In addition, rollers can be used instead of fixed electrodes between which the material to be joined is automatically traversed and a fusion weld made in the form of a straight line.

There is another method of fusion welding for joining sections together end to end. This is very much the same in principle, except that the current intensity is greater owing to the thicker material, and the two ends are forced together during the heating period until they fuse into one solid mass, the current being automatically cut off when the right temperature has been maintained sufficiently long. This method of jointing is now suitable for dealing with very high pressure and is used for joining steam headers and tubes together quite satisfactorily.

Other methods of joints, the folded seam, brazing and soldering are applied only to light sheet work and are dealt with in other parts of this series, so that it is not proposed to go into them here.

BENDING STEEL

The most common operation in steel manipulation is bending in one form or other.

Bending is used to give steel a specific shape preparatory to welding, riveting or bolting. It is used to form cylinders for the manufacture of drums, tanks, ducting, etc., for bending angles to make flanges or channels and girders for arch supports or stiffeners, or any other operation requiring the material forming into a shape other than that which can be manufactured by joining flat plates together.

Whatever type of bending is used it must be remembered that the bent part, or piece, is physically changed as a result of the operation performed upon it, and this change may, and usually does, affect its strength.

For instance, if an ordinary steel bar is bent at a right angle the crystal structure of the steel at the bend undergoes physical deformation. Some of the crystals are stretched lengthways to form the outside radius,

some are compressed on the inside radius, whilst those along the centre line remain more or less at rest or in their original state.

This means that when bending metal, a state of tensional stress, compression stress and neutral or unstressed area exists, and it is sometimes necessary

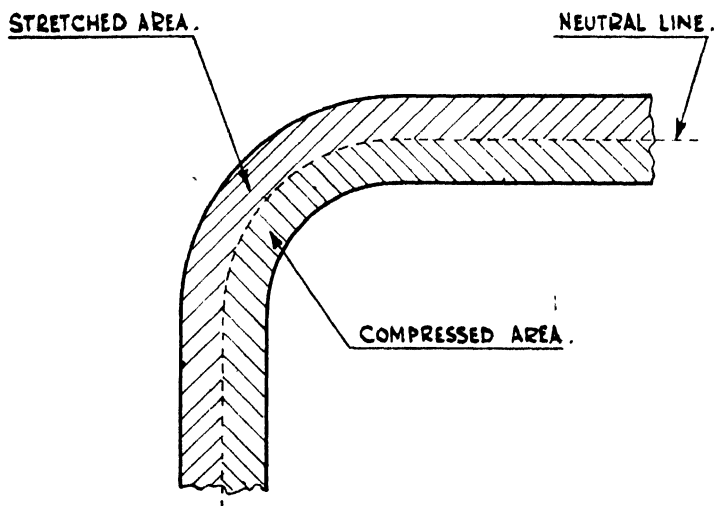


FIG. 19. DEFORMED STRUCTURE OF BENT PLATE

to release these stresses by heating to anneal or normalize the steel. Otherwise the reduction in strength may result in certain members being unsafe.

A great deal depends on the type of steel. Those high in carbon, and many of the alloyed steels, may require heating before bending because their structure is too hard to allow the crystals to take up a new formation without parting, causing cracks, whilst soft annealed steel can stand very considerable deformation without showing any signs of cracks. An example of this is the soft steel plates used for pressing out motor car bodies. These can be pressed into a variety of very deep

pressings without any sign of cracking and very little thinning.

The point to be borne in mind when using bending tools is that the steel is elastic up to a certain limit and when bent will recover to a certain extent and tend to spring back towards its original form providing it is not bent beyond its elastic limit. It is, therefore, usually necessary to bend it slightly beyond the finished position, so that when it does spring back it finishes at the correct angle.

As an example, if a plate is to be bent to a 90° angle it must be bent to an angle greater than 90° , probably another 6 or 7 degrees beyond, so that when it springs back it will finish up at the exact 90° . Only experience can indicate exactly how far this over-bending must be applied, because so much depends on the type of material and, to a certain extent, on the machine. In addition, the thickness of the steel will have a marked effect in two ways, first the greater strength and secondly the strength of the bending machine itself. Unless the bending machine is stiff enough it will tend to spring and give added difficulty in getting an accurate finished bend to a correct size.

When annealing alloy steels, especially if they have to be heated for bending, it is advisable to ask the advice of the makers of the steel regarding the suitable working temperature, because it is very easy to ruin any special steel by incorrect heat treatment.

BENDING MACHINES

Fig. 20 shows a modern set of plate curving rolls. The particular one illustrated is suitable for handling plate 1 in. thick $\times$ 16 ft. long. The operating gear, it will be observed, is centralized, which allows the operator to control the whole of the operations without moving from the central position.

There are various makes of curving rolls on the market; most of the modern ones are gear-driven with a direct coupled motor, though some are still belt-driven. The drive is on the top roller through a gear-box, driven through a clutch arranged to slip when overload comes on. The plate is placed into the rollers and run backwards and forwards, and the centre roller



FIG. 20. PLATE BENDING ROLLS

is gradually lowered as the radius of the bend decreases until such time as the plate is bent to a complete circle.

In some machines it is necessary to bend up the leading edge of the plate by hand because it is not possible to run the plate between the rollers right to the edge, owing to the fact that with the top roller being mid-way between the two bottom rollers the plate would fall out of the machine when it passes the centre line of the top roller.

To get the completed cylinder from between the rollers the machine is arranged for the end bearing to

be opened out and the finished work slid along the rollers to clear the machine.

Vertical rolls are also used with either three or four



FIG. 21 ANGLE CURVING ROLLS

rollers, usually for heavier plate, because it is easier to handle the weight with a plate hung vertically from the crane hook than in the horizontal position.

Fig. 21 shows an angle bending machine which is used for bending sections or bars, and this also can be

either three- or four-roller type. The radius of the bend is obtained by closing the gap between the centre roller and the two outer rollers gradually, as the work proceeds, until such time as a complete circle is produced. This machine is used for making angle flanges or any radial work on rolled steel sections.

Fig. 22 shows a plate folding machine which is one having a very large variety of applications, in fact, it is probably the most used machine in a plate shop because it has such universal application for handling all sorts of bending problems.

Below the illustration of these two machines (and also of that in Fig. 23) are shown a few of the shapes which can be formed on them. The plate folding machine, in particular, offers great scope for the ingenuity of the operator in its manipulation. In fact, short of making actual circular pieces, practically any shape can be obtained on a folding machine. The upper beam is designed so that it can be swung out, thus enabling enclosed shapes, such as deep channel sections, to be withdrawn. Curved or conical sections can be formed by giving the plate a series of slight kinks at short intervals.

The press brake shown in Fig. 23 also comes under the heading of plate bending machines, although its operation is somewhat different from the accepted meaning of plate bending. It is capable of producing any number of shapes by forcing a former into a die. The design of this, however, requires careful consideration and experience to ensure that the steel will draw to the extent required and also that the sequence of deformations is such that it will allow sufficient material to be left free to form the other part of the shape without tearing. In addition, consideration of costs arises because unless there are a sufficient number of pieces to warrant the expense of making the press tools, it is not an economical proposition.

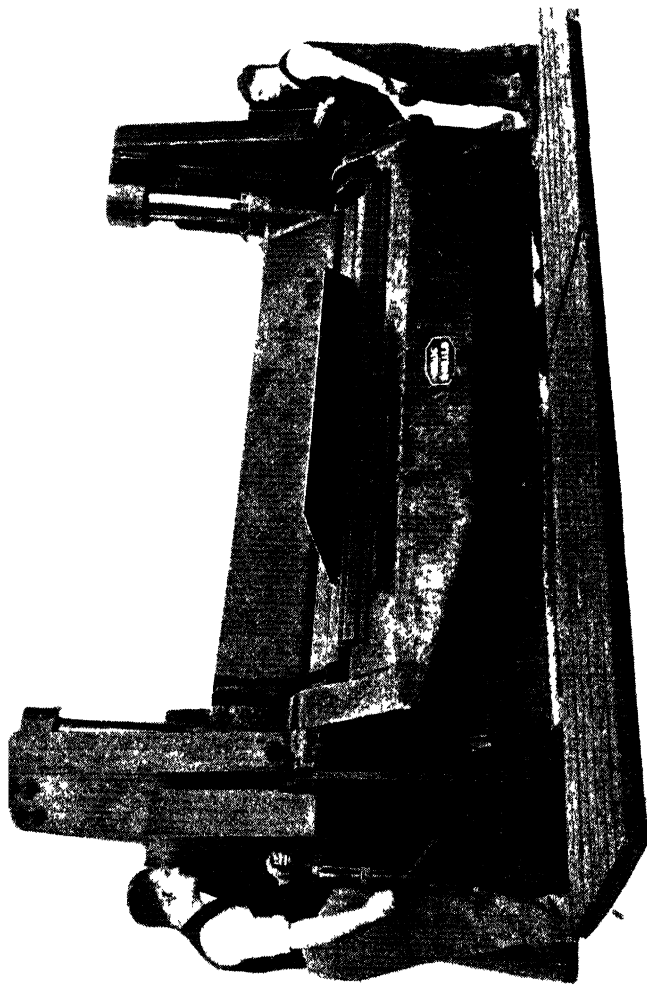


FIG. 22. PLATE FOLDING MACHINE

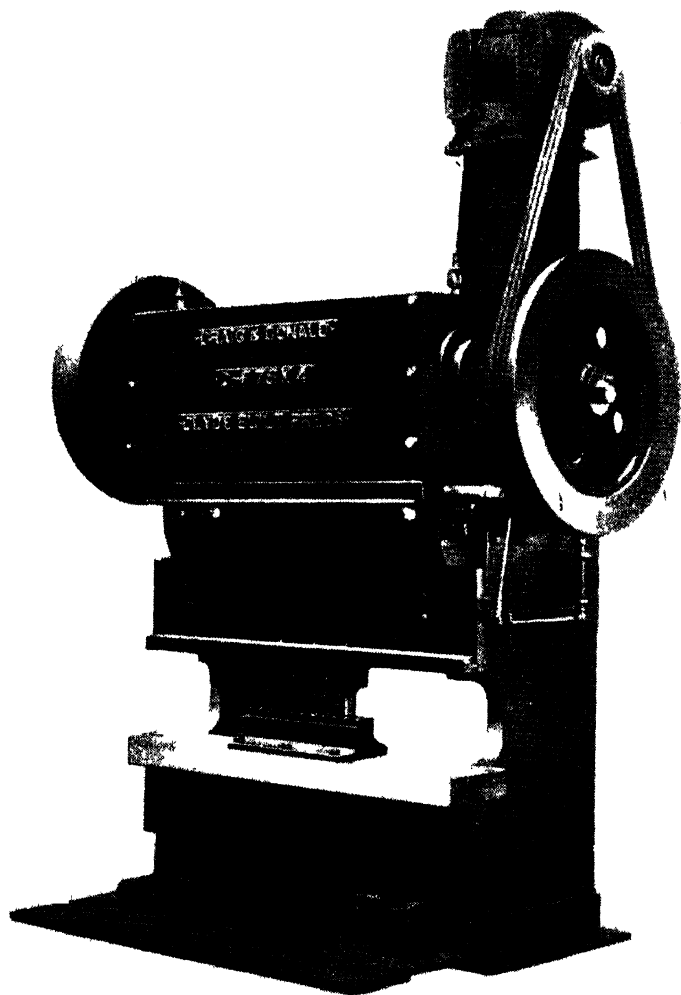


FIG. 23. 75-TON PRESS BRAKE

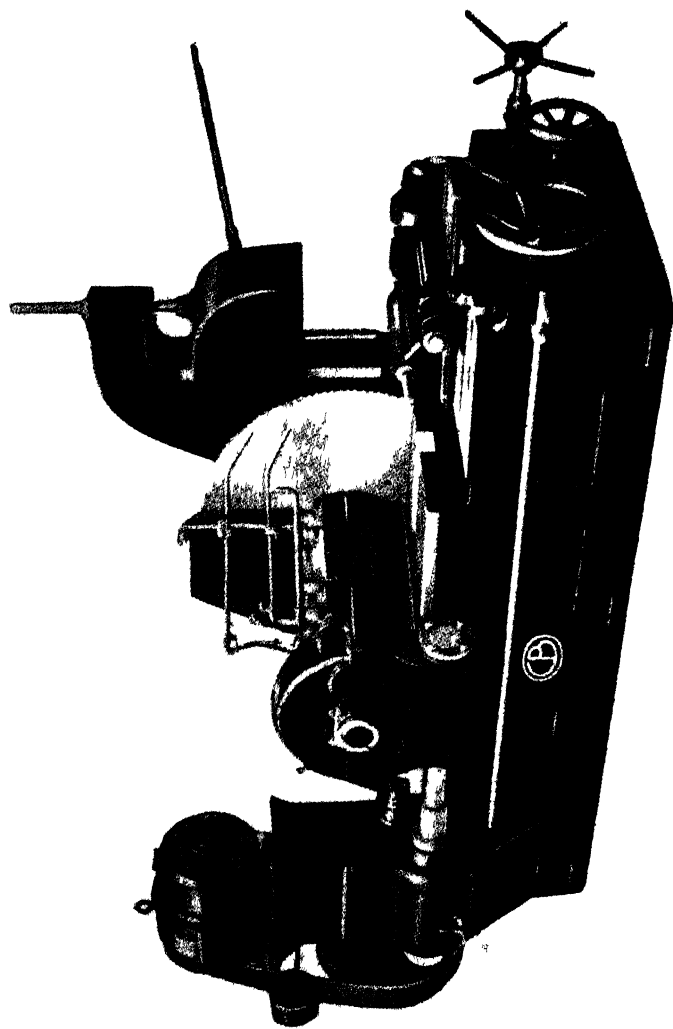


FIG 24 MODERN CIRCULAR SAW

Punching work can also be carried out on a press brake.

The foregoing are the principal machines for bending of steel. There are, of course, others having special features for rapid production work, but they would not be used for ordinary jobbing work.

SHEARING OF STEEL

We next come to the various machines designed for cutting or shearing plates and sections, of which there are a great variety that can be roughly divided into two groups—those which cut by means of a drop blade or guillotine and those which cut by means of a revolving tool such as a circular saw.

Fig. 24 shows a modern circular saw which has an automatic feature in the form of a fluid feed control which ensures that the maximum rate of feed is maintained according to the thickness of the material being cut.

For instance, in cutting a joist section which is mounted in an upright position on the table of the machine, the flange would meet the saw first at the toe, and this being of thin section would offer little resistance and consequently the cutting speed would be high. As the saw advances through the section, it would reach the web and the thickness of metal to be cut would be considerably increased.

The cutting speed under this additional load is then automatically reduced by means of a fluid control to suit the increase in thickness of the material, but at the same time maintaining it at the highest cutting speed possible in relation to the thickness being cut.

As soon as the web is cut through, leaving the remainder of the flange only to be cut, the speed automatically increases to suit the thinner section of the flange. By this means, the maximum cutting speed is

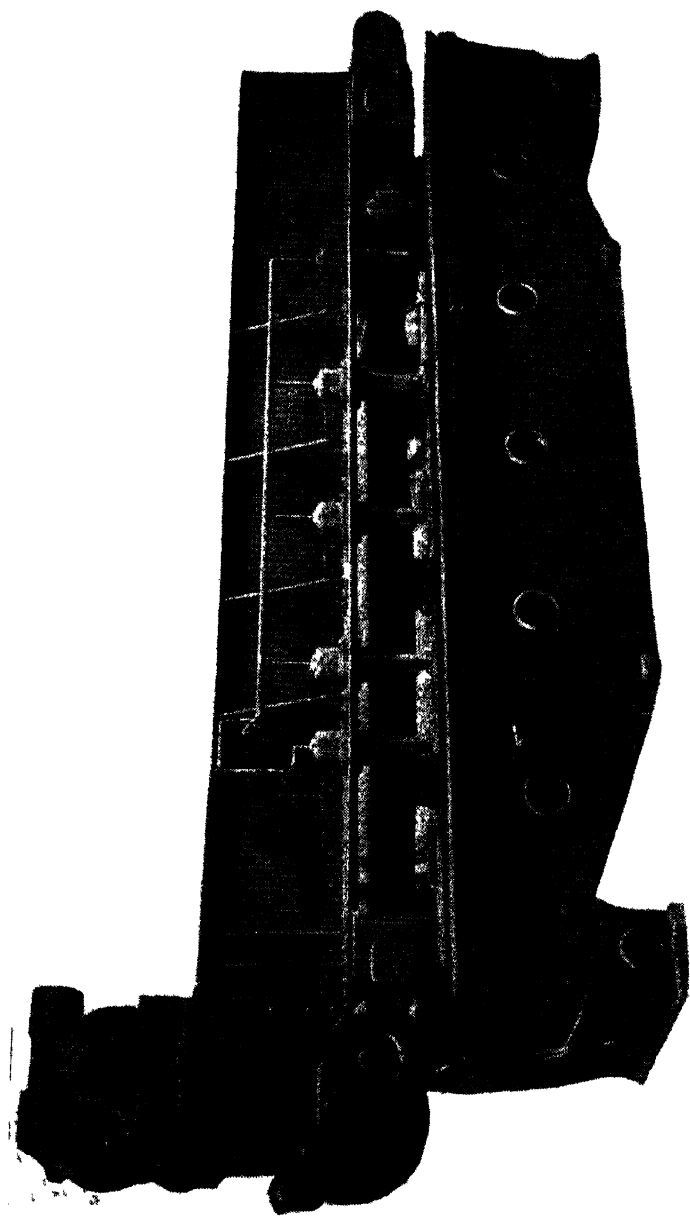


FIG. 25. PLANO-GUILLOTINE

always maintained consistent with retaining the saw teeth in good condition. Obviously this is just as important as fast cutting, as otherwise much time would be lost in re-sharpening saws.

Fig. 25 illustrates a plano guillotine. This is a relatively new machine designed for shearing the edge of plates and has the advantage that the edge of the plate is cut square or can be bevelled for providing the Vee for welding. The operation is carried out by means of a travelling circular cutter which is drawn along the edge of the plate very much like a knife along the edge of a table, the material to be cut being held in position by means of pneumatic clamps.

The other type of machine for cutting plates is the ordinary guillotine shear, which consists of the drop blade method, and whilst this is a very satisfactory machine great importance is attached to the necessity for keeping the blades sharp, otherwise, as a blunt blade descends, there is a tendency for it to push the plate away rather than cut clean through it. This results in the edge of the plate being cut out of square and requiring retrimming.

Fig. 26 shows a circular plate cutting machine. This is an extremely useful machine because practically any shape from a circle to an intricate combination of radii can be cut without any difficulty. It is merely a matter of the operator's ability to feed the plate in such a way that any desired shape can be cut.

It consists of two circular rotating cutters, the gap between them being adjusted to suit the thickness of the plate to be cut.

Following this machine, there are the various forms of punching machines and croppers which are in general use, and which are probably sufficiently familiar that an illustration is not needed. In addition there are the angle straightening machines, angle croppers, angle

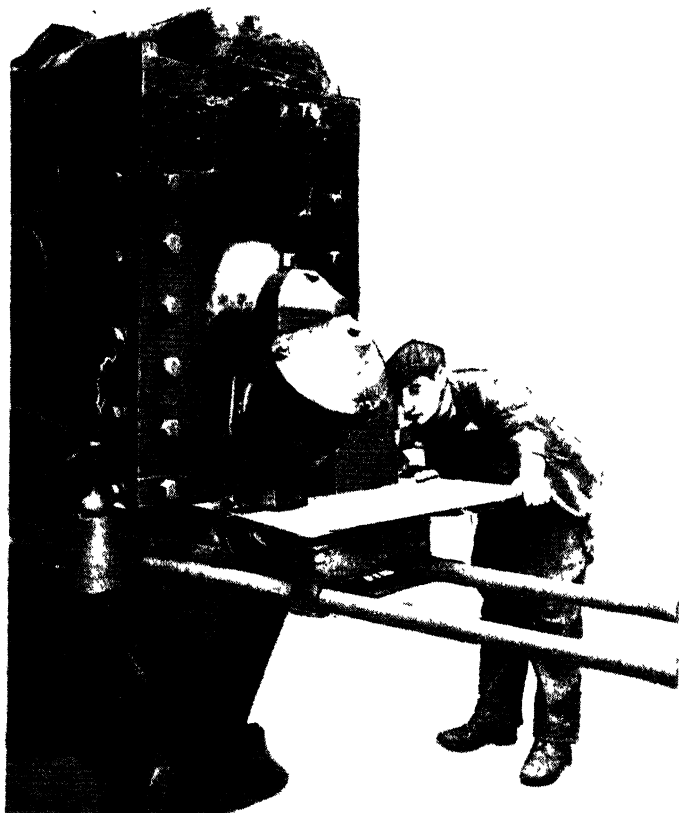


FIG. 26. ROTARY SHEARING MACHINE

bevellers and numerous other special machines all having a particular use in plate work.

TEMPLETS

As the paper pattern is to the tailor so is the templet to the plater. In other words, it is his pattern to which he must cut and shape each item he requires.

Templets are full-size lay-outs made of paper,



FIG 27

wooden laths, metal, or cardboard, depending on the size and frequency of use, and on the rigidity required.

Fig. 27 shows a templet maker at work on the templet for a bunker. As can be seen, he first of all marks out the outline and centre lines on a wooden floor (which is kept smooth and blacked) by means of chalk and string.

Having done this, he then sets out the wooden laths and tacks them together over the outline.

From there he proceeds to mark on to the wood the centre lines of all the holes, points of intersection with the adjoining members, and all the information necessary to enable the plater to mark off his steel preparatory to cutting and drilling.

By means of a code the templet maker is able to convey to the plater precisely what work is required and at what stage it should be done. For instance, it may be that certain bolt holes have to be drilled or can be drilled to begin with, whilst others must be left until assembly is advanced and the correct position marked off. Again, the code can indicate whether the piece is left-hand or right-hand by means of different coloured crayons, or other suitable mark.

A typical code is as follows—

- + Rivet.
- ⊖ Open hole for site riveting or bolting.
- ⊗ Hole countersunk on near side.
- ⊕ Hole countersunk on far side.
- ⊗ Hole countersunk both sides.
- Tapped hole.
- ⊖ Hole diameter varies, the size of the hole usually being written alongside the mark.

Holes could be circled, say, in blue crayon to represent the right-hand side and in red to represent the

left-hand side. This means that only one templet need be made, and all that is necessary is just to turn it over to get the requisite handling, as obviously it is of great value to be able to cut and drill plates in bundles as far as possible.

Further, the back marking and the position in which the templet is to be placed on a rolled steel section, say, on the heel of the angle, is also denoted by a mark along the edge of the templet, meaning that it is to be placed at the heel of the section. Where strips of wood are used, blue marks indicate length and red marks width. Marks such as     are used to denote the size of the holes, or whether a templet is to be used for more than one bar.

Again, where it is cross-hatched or marked LWC denotes chequer plating, and dimensions underlined mean that it has been altered or is not to scale.

The templet maker can do a great deal towards ensuring accuracy and speed of production as well as forming a very good check on the drawing office against possible drawing errors.

In some works, of course, the plater does his own templets and carries the job right through, whilst in others there are specialists engaged solely on this work in a separate templet shop, or loft as it is sometimes called. This all depends on the lay-out of the works and the particular type of work being done.

ASSEMBLING

Having reviewed the various methods of manipulation and machining of plates and sections, let us now apply these to an actual fabrication in the sequence in which they would be used, and observe how each machine can be used to the best advantage, or why it should not be used.

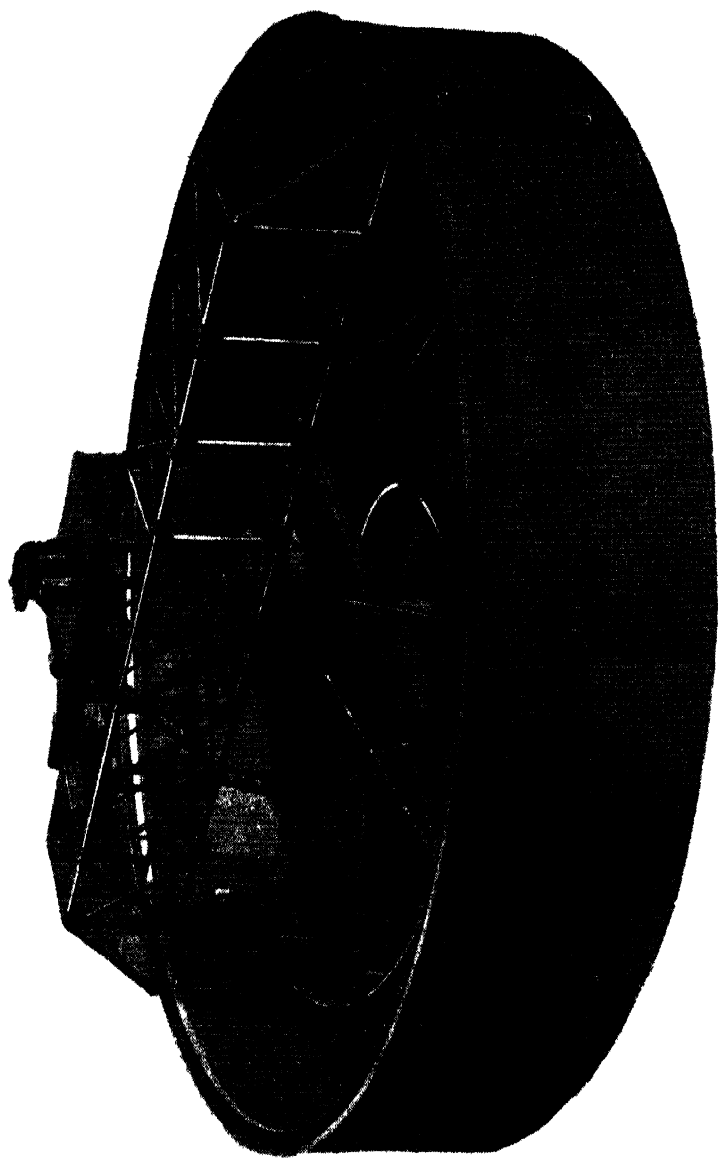


FIG 28

Fig. 28 shows a large settling tank made of plates and sections, and we will assume that we are in charge of a structural works which has to make it.

Usually the drawings are detailed, as far as actual dimensions go, in the drawing office and in some cases the latter also decide the size of the plates and length of sections which are to be drawn from stock or the rolling mills, although in other cases the plate shop itself is responsible for deciding the dimensions of the stock which is to be used and how it is to be cut up to the required sizes to the best advantage and to leave the least amount of scrap.

This latter is a very important item and one which should be carefully watched when ordering up steel-work. Especially should care be taken of it in the drawing office when designing the position of joints in plate work, the reason being that the rolling mills supply plates up to a certain width, usually about 5 ft., and charge extra for any width over that, which, of course, should be avoided. In addition large pieces are difficult to handle and so make the work more expensive.

Having fixed the size and ordered the material from the stock yard, the next operation is to make the templets, which may be either of wooden laths or paper. If there is only one of the items to make, paper is probably cheaper, except for the larger pieces, when paper becomes difficult to handle and wood is the best, and in addition can be stored for future use without deterioration.

It is common practice in the plate shop to decide the exact position of the bolt holes and very often the pitch of the holes according to the size of the section, except for special joints. The condition requires that the hole will be far enough from the radius in the bosom of the section to allow the bolt head and washer to

clear without projecting beyond the toe of the section. This dimension is called the "back mark" as shown in Fig. 1, page 194, and is the distance from the back of the section to the centre line of the bolt hole.

The plates have now been delivered to the shop and are ready to be marked off from the templets. This is done by laying the templet on to the steelwork and outlining the shape and position of the holes with either black or white paint. It will be found that the best marking medium is white lead as this does not come off with rust or when the mill scale comes off.

Many shops have a symbol system for marking holes, which indicates whether they are rivet holes or bolt holes. For instance, one may be marked with a "X" and another with a circle, or thus ○ ●.

The plates must now be cut to the desired shape. The first operation is shearing to square them up. Then those which must be shaped, say, with a radius or recess, can either be taken to a notching machine which will cut out small recesses such as corners preparatory to flanging up, or, if the piece has to be cut circular, to a circle cutting machine which is virtually a shearing machine having rotary cutters, the plate being fed in between the cutters by hand along the marked off line. The plates which simply require squaring are cut on either a guillotine shear or a plano-guillotine, the latter having certain advantages, the principal being that it cuts a square edge without any turning down of the edge, which guillotine shears are inclined to do unless the blades are kept sharp.

If the tank is to be riveted then the corners of the plates are swaged down to reduce their thickness so that at the point where the four plates meet they can be riveted together and the joint will be kept about the same total thickness as two plates overlapping would be. For this swaging down the corner is either heated in

a fire or with a flame and hammered down to the right thinness by hand.

After this the bolt holes or rivet holes are either drilled or punched, whichever machine is available. If drilled, the plates are usually bundled together, the top one only being marked and the drill goes through the whole bundle.

In the meantime the rolled steel sections are being handled, those which require drilling with a large number of holes being handled under a girder drill, which is a multiple drill having a number of drilling heads to drill the holes simultaneously.

The sections can then be rolled to the radius of the outside of the tank. This can be done in curving rolls if available or by hand by the blacksmith. The former is the better and cheaper, the rolling being done to a templet, as shown in Fig. 21.

This same templet can now be used for curving the plates in the curving rolls.

All is now ready to start assembling, and the first and most vital operation is to set down the centre line or datum and the principal dimensions. It is fatal to start building and to assume that because all the parts have been made to a drawing size that they will come together and that the overall dimensions will look after themselves. As explained under the heading of "Types of Joint," owing to the clearance which must be allowed in the bolt and rivet holes, work will tend to grow unless constantly checked as each item is added.

For this reason everything is fastened up in position with a few bolts only so that these can be slackened off, as the structure grows, for adjustment to give the correct overall length in relation to each piece. After the whole has been tacked up the full number of bolts can be put in and properly tightened.

This applies equally to making a riveted joint. It is important that rivets should be driven in at intervals, starting at one end and doing a few, then at the other end and doing a few, then intermittently across the whole of the joint. Otherwise, if riveting is started at one end and continued right to the other end, doing each succeeding rivet, it will be found that in a very short time the rivet holes do not register owing to one side moving forward slightly. This is caused by the rivet, when it is being driven, filling up the clearance in the hole and tending to push the plate one way or the other in the direction of least resistance.

The same applies to welding a long seam, particularly a circular vessel, but the growth in this case is due to expansion caused by the local heat generated at the point of welding. It is necessary, therefore, to apply intermittent welding so as to tack up the whole of the article being welded before completing the weld.

When the complete assembly is too large to be transported in one piece and has to be dismantled for shipment and re-erected on site, consideration must be given to the position of the site joints and to the sizes of the pieces which have to be transported and handled by the erector, bearing in mind that lifting facilities are very often non-existent and that tackle has to be rigged up by the erector. It is important, therefore, to remember that the cost of erecting outside is much higher than in a works, where there are usually cranes and other tackle available, and to see that the pieces can be handled easily without undue rigging and tackle.

Another very important point which will save time is the careful marking of all the items in the sequence of erection. This saves much of the erector's time in sorting out and avoids the necessity of the erector having to refer to drawings unnecessarily.

SECTION XXVIII

THE MECHANICAL HANDLING OF MATERIALS AND PRODUCTS

BY

WILLIAM H. ATHERTON, M.Sc., M.I.MECH.E.

SECTION XXVIII

THE MECHANICAL HANDLING OF MATERIALS AND PRODUCTS

(a) CRANES

IN a heavy engineering works the raw materials and the larger parts of machines in course of construction are transported from one shop to another mainly by the aid of low trolleys, or four-wheeled bogies, and railway wagons. These usually run on standard gauge rail tracks, turntables being arranged here and there near shop doors in order to permit of right-angled turns of the bogies.

For some yard operations a Ford tractor is handier and more economical than a steam locomotive. An electric capstan equipped with a long wire rope is also a useful appliance for hauling trucks along a works siding. In some yards mobile petrol-electric jib cranes can be employed with advantage, their flexibility being remarkable. A "Rapier" mobile crane of light type is outlined in Fig. 1.

When scheming out the general lay-out of an engineering works it is advisable to arrange the machine, erecting and packing shops so that both railway wagons and the largest motor lorries can run under a travelling crane, in order to permit of the prompt unloading of materials arriving on the premises and the rapid loading up of finished goods leaving the works either in packing cases or loose.

The raw materials of a plating and structural

shop engaged on medium work are mainly plates, from $\frac{1}{8}$ in. to $\frac{1}{2}$ in. thick, and steel sections comprising flats, angle bars, channels and joists, in lengths of 18 ft. and upwards.

The products of this shop include girders, trestles, columns or stanchions, and platforms, also conveyor

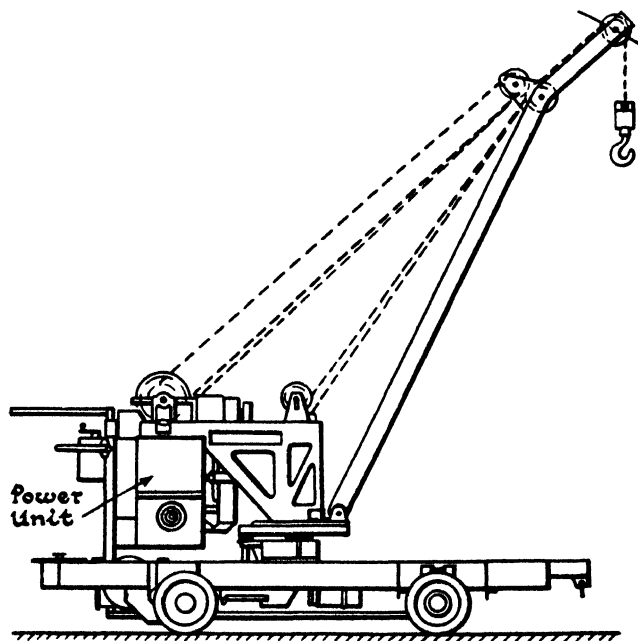


FIG. 1. "RAPIER" MOBILE CRANE

and elevator frames, elevator casings or housings, troughs, bins or hoppers, and lastly chutes of many shapes and sizes.

All these materials and products are commonly handled by overhead cranes, using various forms of slings, hooks, and clips. A useful auxiliary appliance is the "lifting magnet," which is sometimes used in conjunction with a jib crane or an electric telfer

for handling steel plates and bars, as well as pig iron and scrap without the aid of slings.

The raw materials of an iron foundry are mainly sand, coke, coal, pig iron, scrap, and firebricks; while timber and plaster of Paris (a cement) are required by the pattern shop. The products of a foundry are castings ranging from a fraction of a pound in weight up to several tons.

It is not usual or economic, however, to produce both light and heavy castings in the same foundry. In order to achieve financial success it is necessary that the buildings, the equipment, and the men employed should be specially adapted for only a limited range of work. Big castings are handled by cranes and heavy bogies. The economic transport of castings in light mass-production foundries will be considered later in some detail.

Some engineering works and foundries have been equipped with an extensive system of light narrow gauge rail tracks and trolleys; but such tracks have been rendered largely unnecessary by the development of petrol motor vehicles and of the convenient electric accumulator or storage-battery trucks which are now so much used. The latter are far more mobile in operation than are rail trucks, though they need good roads to run on, preferably of concrete construction.

Inside the shops one picks up the various loads from trolleys and trucks by means of an overhead travelling crane (using suitable rope or chain slings) and quickly moves them to the positions required for machining operations or otherwise, with a minimum of exertion.

Fig. 2 shows in elevation and part plan a good type of electric overhead traveller, as made by Herbert Morris, Ltd., Loughborough. Here the crane driver sits in a cage at one end of the girders, where he

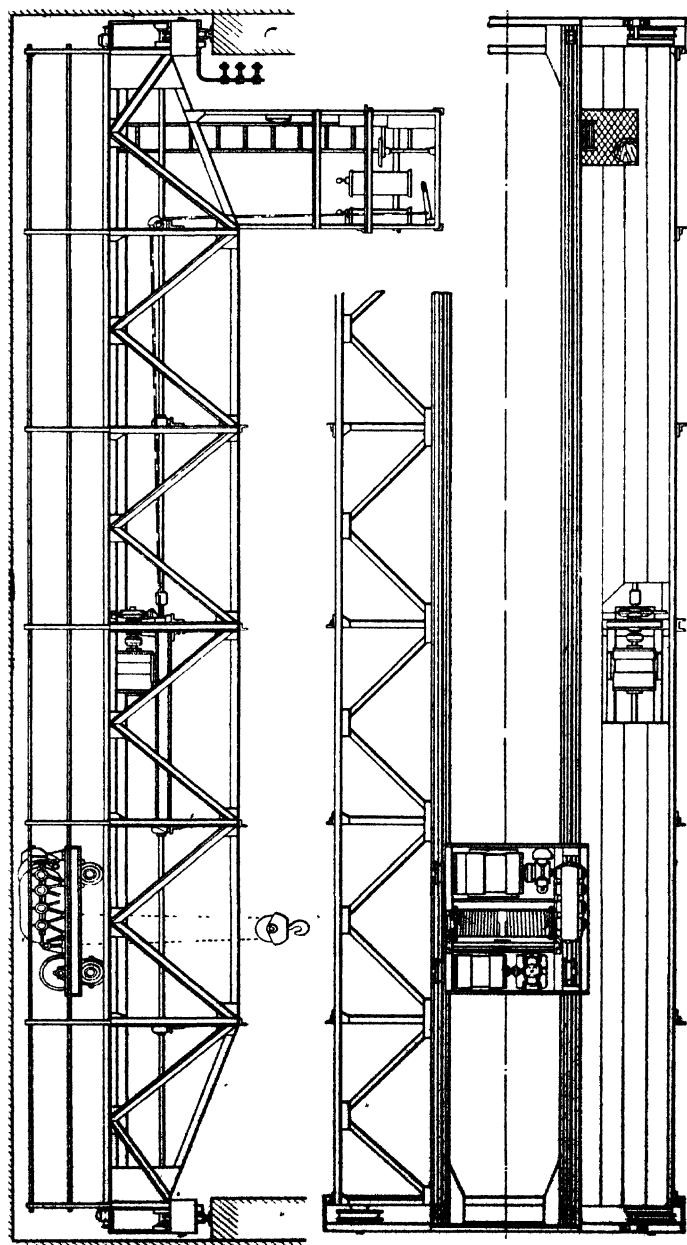


FIG. 2. ELECTRIC OVERHEAD TRAVELLER

commands a good view of the load on the hook and operates the control gear at hand as required. Many of the lighter travellers, however, have several ropes hanging down to arm level for operating the different motions of longitudinal travel down the shop, traverse across the bay, lifting and lowering the load, thus dispensing with a cage and its occupant.

In heavy foundries similar arrangements are made for moving castings many tons in weight by means of trucks and cranes; though different methods are adopted in light repetition foundries, where half-ton iron barrows and 2-ton electric battery trucks are extensively utilized for the transport of quantities of small castings inside the works.

Fairly light jobs may be picked up from the floor by auxiliary jib cranes supported by the shop columns, such cranes being conveniently placed to serve individual machine tools or a small group of machines. The proper functioning of light cranes is facilitated by the growing practice of driving tools individually with motors, thus eliminating belts and overhead shafts.

A simple overhead hand crane is seen in Fig. 3. This type is suitable for places where head room is very restricted, as below shop galleries. A trolley carrying a hook and lifting gear runs on the bottom flange of a steel joist, and is operated by a hand chain hanging down to nearly floor level. Another pendent chain controls the longitudinal motion of the entire crane down the shop.

A light cantilever jib crane is indicated in Fig. 4, this type being often styled a "foundry" crane, though much used elsewhere than in foundries. Here the horizontal trolley track, formed by a pair of steel channels, is struttet below to the foot of the post. The position of the trolley is controlled by a "racking" chain, which winds on to a barrel fixed to the top of the post.

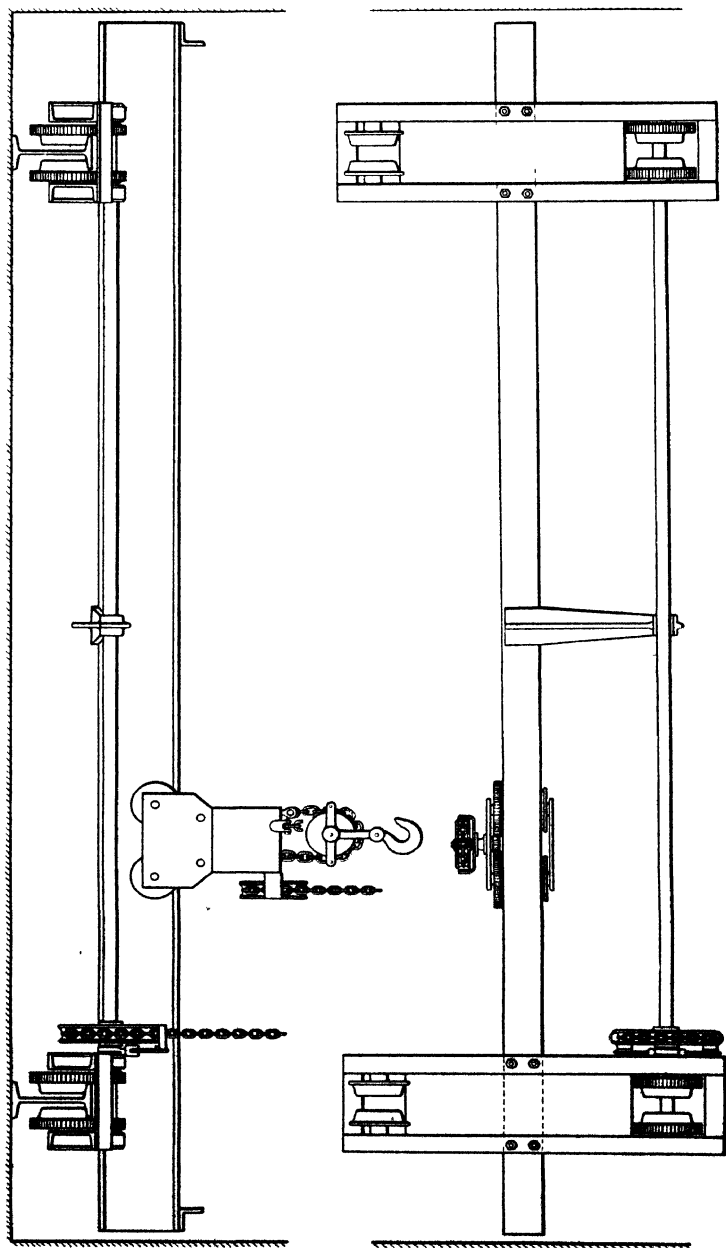


FIG. 3. SIMPLE OVERHEAD HAND CRANE

This barrel is geared to a spider wheel *D*, rotated by a pendent hand chain *E*. The return racking chain runs over a guide roller at the outer end of the jib. The crane post is pivoted at top and bottom and can "slew" or turn through an angle of fully 180 degrees. Double-reduction hoisting gear is fixed to the post.

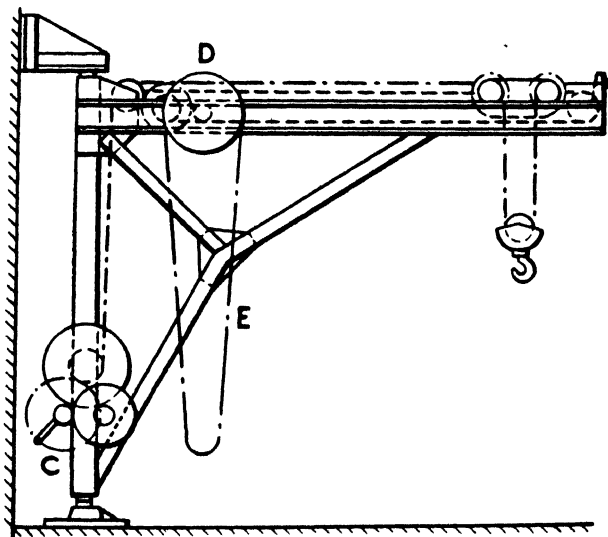


FIG. 4. FOUNDRY JIB CRANE

at *C*, the lifting chain being coiled on a barrel at one end and anchored to the tip of the jib at the other end. For controlling the load a hand brake is fitted, as well as a ratchet wheel and pawl. Manual power, however, tends to be displaced more and more by electric motors, even on light cranes. Hand cranes are too slow and expensive for modern requirements, unless a lift is wanted only at infrequent intervals.

When building heavy engineering shops it is a good plan to provide a secondary or high-level gantry running the full length of the bay, as shown in Fig. 5,

and to equip it with an auxiliary crane. The upper crane can then pass over the heavier crane on the lower gantry and thus serve either end of the shop as may be needed. It will also be available for lifting parts of the big crane when the latter is in course of being overhauled or repaired from time to time.

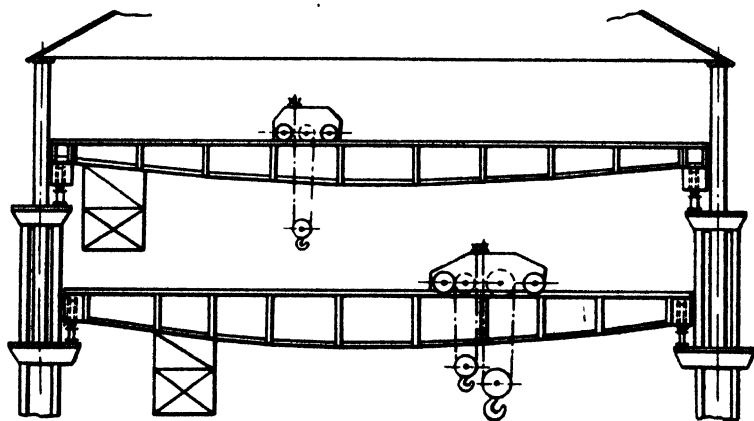


FIG. 5. HIGH AND LOW LEVEL WORKSHOP CRANES

(b) WATER SUPPLIES

Although water is not commonly regarded as a raw material, yet the necessity of ensuring an ample supply of water in one way or another must not be overlooked when laying out an engineering works or a foundry. It is not wise to rely entirely on a town supply, which is liable occasionally to be cut off or restricted. Moreover it is rather expensive, seldom costing less than 6d. per 1000 gallons, as registered by a water-meter, and sometimes far more. For steam generation town water is often too hard, and may need chemical treatment in a water-softening plant.

If a river, canal, or other source of supply is not available, then one should collect rain water from the roofs of the shops in wet weather, and store as much

as possible of it in big tanks, to form a reserve supply. In addition it is necessary to build a cooling tower of some kind, for keeping down the temperature of the circulating water from the surface-condensing plant, and making up the loss by evaporation from the town water supply. Hard water must be kept out of water-tube boilers at all costs.

Furthermore, it is sometimes wise to sink a bore-hole some hundreds of feet deep and to fit it with a deep-lift pump, delivering into an elevated storage tank erected on the top of a tower. This high-level water is then available for supplying the Grinnell sprinkler service throughout the works for extinguishing fires, as well as for general foundry purposes; even though it may be too hard without suitable treatment for steam generation and for culinary operations in the works canteen.

(c) **WEIGHING MACHINES**

Since all engineering materials and products have to be weighed at least once, it is usual to install one or more platform weighing machines in some part of the works, so as to enable goods entering and leaving the premises to be conveniently weighed, either in railway wagons or on motor vehicles. Coal, pig iron and steel bars commonly arrive by rail, and should always be weighed in.

At the road entrance to the works a useful size of machine to install is a 20-ton weighbridge, having a large platform at yard level and a steelyard inside the time-office, under the control of the gate-keeper. The platform should be made big enough to accommodate motor lorries of long wheel-base. The alternative is, to take separate weighings of the load on each pair of wheels; but this takes up more time and involves greater liability of error.

Smaller fixed weighing machines, or "direct-reading scales" equipped with large graduated dials a yard in diameter, are much used for rapidly weighing barrow-loads and trolley-loads of castings or other details. A useful size weighs up to 3 tons. Moreover, a convenient type of portable dial weigher is available for weighing jobs whilst slung from the hook of a crane.

Some types of machines, known as "continuous weighers," can be fitted to conveyors, so as to give an automatic and continuous record of the amount of coal or other loose material travelling along a belt, on its way to a storage bunker or otherwise. When the rate of passage of the coal is fairly regular these continuous weighers give results sufficiently correct; though the automatic hopper type of weighing machine is certainly more accurate, but less convenient to install, as it requires more headroom.

Finally, there are some very clever little weighing machines built, styled "counting scales," that are capable of counting a vast number of small articles, such as little screws, bolts and pins, ten or a dozen of which (whose weight is known) are put into an auxiliary pan and used as a "poise" against perhaps hundreds or thousands of them which are put into the main pan of the scales to be counted. The total number of articles can then be read off a scale directly.

The construction of large weighing machines and scales, in all their vast variety of types and applications, has indeed been developed into a very specialized branch of mechanical engineering by the inventive ability and business enterprise of a remarkably small number of firms.

(d) FUEL SUPPLIES

The fuels burnt in engineering shops and foundries are not confined to raw coal. They include also small

screened gas coke for smithy fires, large furnace coke for cupolas, town gas and oil for small heating furnaces, and lastly producer gas and pulverized coal for annealing and melting furnaces, as well as for steam generation.

Gas and oil enjoy the merit of being easily led in any direction in pipes, the quantities used being measured in suitable meters. Powdered coal can be prepared close to the point of application, and delivered at once into the furnace (as in Herbert's "Attritor" system). Alternatively a large coal drying and crushing plant may be erected in a central position, and the storage bins connected up to long pipe-lines serving several furnaces in different foundries and annealing shops. This alternative, however, necessitates a big initial capital expenditure.

A centralized crushing plant for preparing powdered coal involves a quite complex system of mechanical handling equipment for conveying the small raw coal from railway wagons to the raw coal bins and from these to the driers and pulverizers. Then the crushed coal is led to the separating cyclones and the powdered coal storage bins. Finally, the fuel passes from the bins, through measuring apparatus, to several pipe-lines serving the various furnaces by the aid of pressure fans and the agency of air currents. Space here does not permit of a detailed description of such a plant.

(e) BOILER-HOUSE ELEVATORS AND CONVEYORS

If a boiler-house contains only one or two Lancashire boilers equipped with mechanical stokers, it is unnecessary to install a conveyor at all; though a simple inclined bucket elevator may well be used, delivering through chutes into the stoker hoppers on the boilers.

When four or more boilers are present, however, it

is usual to introduce a horizontal conveyor fed by a bucket elevator erected at one end of the boiler-house, as shown in Fig. 6. Coal is dumped into a hopper in front of the elevator and passes into its foot or bottom

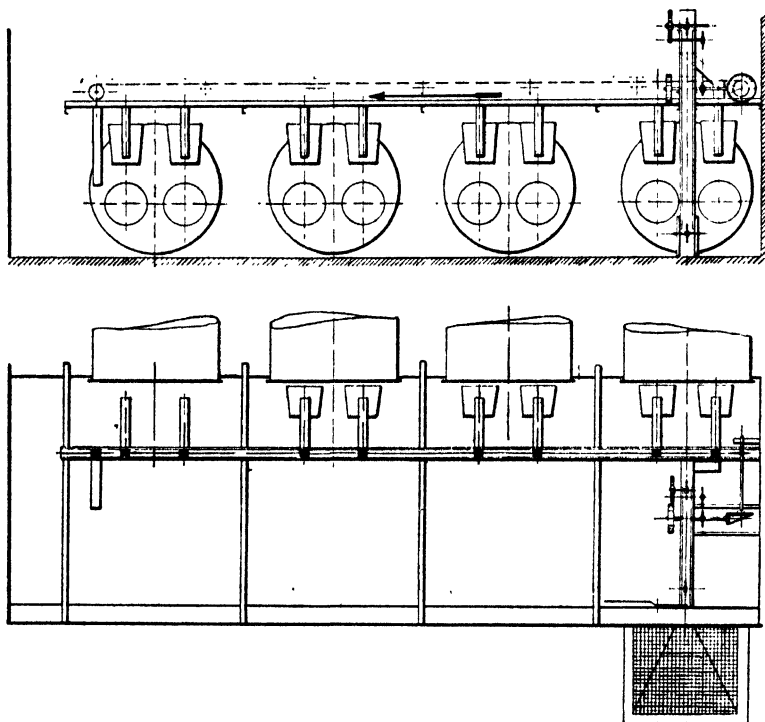


FIG. 6. TYPICAL LAY-OUT OF BOILER STOKING PLANT

boot, either directly or through a suitable feeder, so as to prevent choking the outlet of the hopper, or else flooding the buckets by a rush of coal. The coal is dredged up from the boot by the moving buckets, raised in a constant stream to the point of discharge, and delivered down a chute into a conveyor trough.

Fig. 7 shows sections of both open and cased elevators.

A sheet steel casing enclosing the buckets is effective in keeping down the dust to a minimum.

An ordinary inclined elevator for raising small coal has either pressed steel or malleable iron buckets,

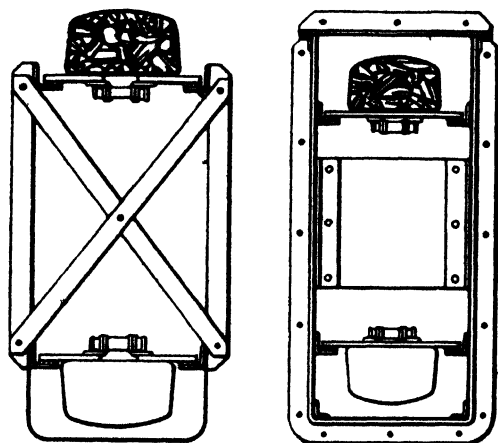


FIG. 7. SECTIONS OF OPEN AND CASED ELEVATORS

bolted at intervals to a single strand of suitable pin chain (Fig. 8) running over top and bottom sprocket wheels; though the bottom wheel can well be a plain roller devoid of teeth.

The elevator chain is usually supported by skidders fixed to the buckets, and sliding on steel angle guides, which may be protected against wear by the addition of renewable steel wearing strips. In big coal elevators, however, one preferably fits rollers to the buckets. Both types of support are shown in Fig. 9.

In small elevators the slow speed head or top shaft is sometimes driven direct by a chain and sprocket wheel, but more commonly it is geared to a short countershaft driven by a belt pulley. The foot or

bottom shaft is carried in sliding bearings by a complete cast-iron or a steel plate boot, provided with a chain tension adjustment operated by two screws.

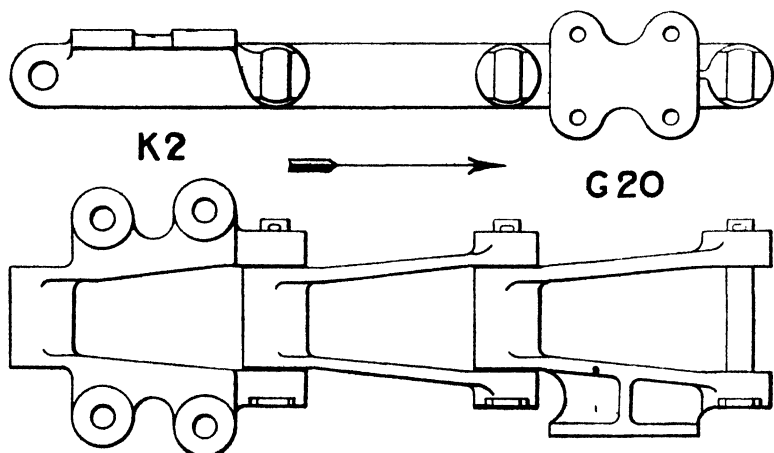


FIG. 8. "GRAY" TYPE PIN CHAIN FOR ELEVATOR

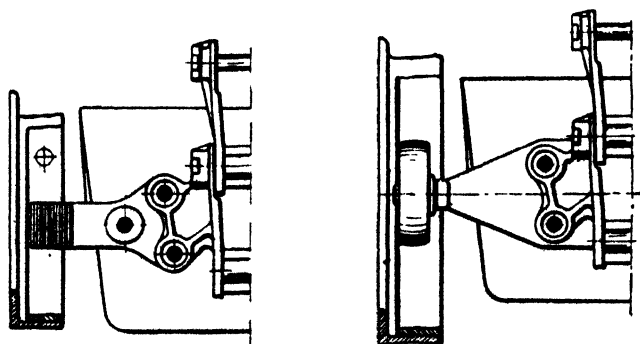


FIG. 9. METHODS OF SUPPORTING BUCKETS

When a large feeding hopper is provided for the reception of truck loads of coal, some means of regulating the flow of coal to the elevator is needed, such

as a sliding door, a jiggling feeder, or a slowly rotating feeder.

Sometimes a crusher is added to break up lumps of coal. This adds considerably to the expense of the plant and the foundations. In cases such as Fig. 6, where only an odd lump or two is accidentally mixed with a large amount of small coal, a simple expedient

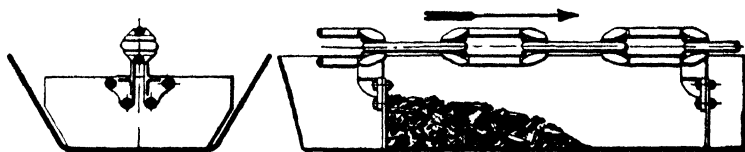


FIG. 10. "DODGE" CABLE CHAIN AND SCRAPER

is to install a stout grid in order to intercept the odd lumps, which can then be broken by hand, instead of blocking up a hopper outlet or a chute.

The coal distributing conveyor shown in Fig. 6 is of the "push-plate" or "scraper" type. A series of scrapers, bolted to an endless chain, are pulled along in a trough, usually made of pressed steel, pushing the coal in front of them, as indicated in Fig. 10. The upper or return strand of chain is supported by rollers at intervals of a few feet, or by skidder bars and continuous angle guides, as in Fig. 11. By providing openings in the bottom of the trough fitted with sliding doors, the coal can be delivered to the eight stoker hoppers on the boilers. There is also an overflow chute at the far end of the trough, as a safety precaution in case the elevator should go on working when all the hoppers are full of coal.

The type of chain shown in Fig. 10 is known as the Dodge cable chain, this being only one of many types of conveyor chains available. Here the links are made of wrought iron or of steel, but malleable cast iron bearing blocks are interposed between the links, in

order to increase the bearing surface and to provide an attachment to the scrapers. This is a "biflex" chain, or one having flexibility in two planes at right angles to one another; and is therefore capable of

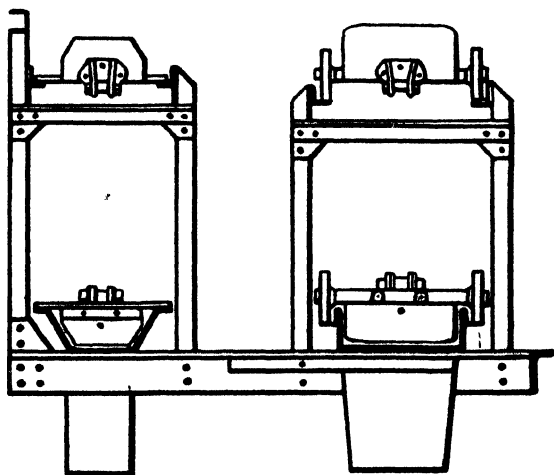


FIG. 11. TWO METHODS OF SUPPORTING FLIGHTS

turning round corners and moving in any direction, whereas an ordinary pin chain is limited to motion in one plane only.

A push-plate conveyor with steel scrapers rubbing on a trough is apt to be very noisy, but the noise may be deadened by fitting hard wood facings on one side of the scrapers. Better still, the push-plates or "flights" of large plants are provided with rollers, running on outside tracks, as seen in Fig. 11, which shows two methods of supporting the flights. Fig. 12 represents the head of a big coal elevator feeding a push-plate conveyor erected over storage bunkers. Both elevator buckets and conveyor flights are fitted with rollers in this job.

Instead of using numerous push-plates and a separate chain one may utilize a U-link chain, which combines the functions of both. Part of a "Bennis" slow speed U-link conveyor is pictured in Fig. 13, the

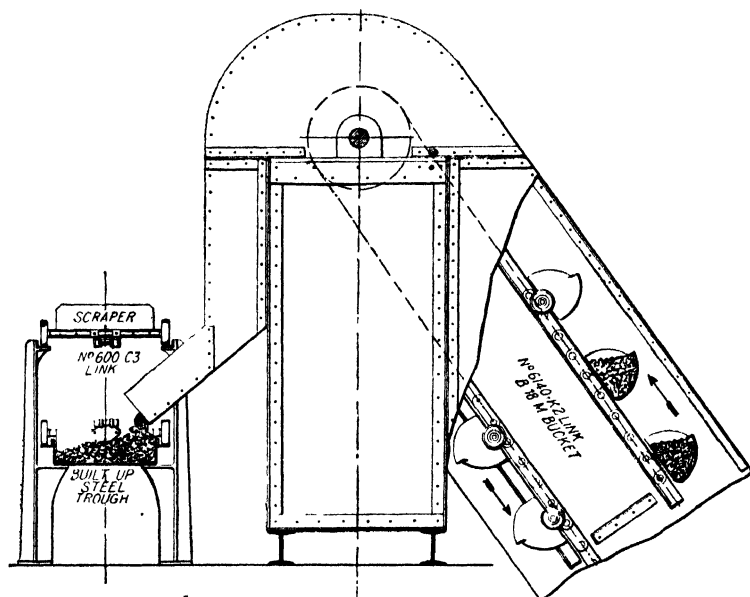


FIG. 12. HEAD OF COAL ELEVATOR FEEDING CONVEYOR

trough here being made of cast iron. Bent steel flats are connected by shouldered rivets to make up a drag-chain.

Another form of drag-chain is the "Redler" cross-bar type (Fig. 14) which has been much used in enclosed conveyors handling powdered coal and granular materials, such as that indicated in Fig. 15. This illustration refers to a conveyor with several feed openings on the top, and also several discharge outlets at the bottom of the casing.

In all drag-link or Redler conveyors of the usual

type, the chain is buried beneath a deep mass of small material, a full load being equal in depth to the overall width of the chain. The chain runs at the slow speed of about 40 ft. per minute. All drag-chains

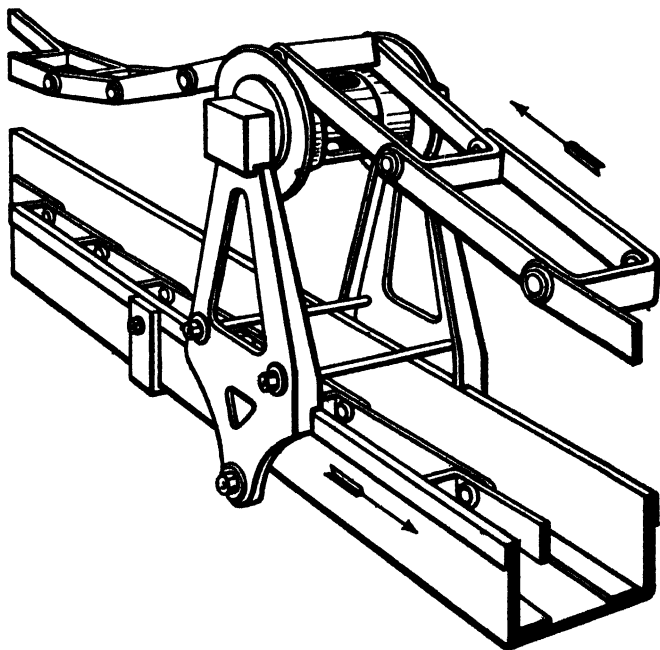


FIG. 13. PART OF "BENNIS" U-LINK CONVEYOR

are relatively wide, open and shallow, sliding in either deep troughs or closed casings.

(f) SCREW, SPIRAL OR WORM CONVEYORS

A spiral conveyor makes a simple and effective distributing appliance, whether for fuel or for numerous manufactured products. It has an ancient history, having been developed from the Archimedean screw;

Archimedes was born over 2000 years ago. It still survives as a convenient and useful contrivance in

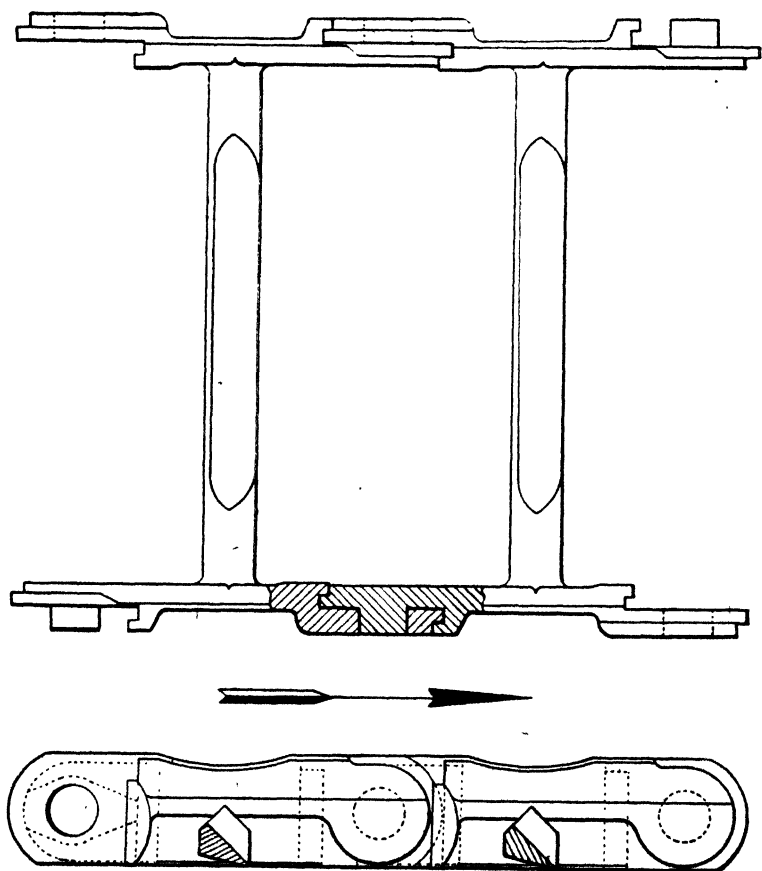


FIG. 14. "REDLER" CROSSBAR TYPE OF CHAIN

its own particular field of service, despite the encroachments of twentieth-century rivals.

A screw or spiral conveyor (Fig. 16) commonly consists of a long twisted steel ribbon, or of several

short flights secured by brackets or by welding to a steel shaft or tube and running in either a pressed steel or a cast-iron trough provided with outlet doors and supported by stools at intervals. The tube or shaft

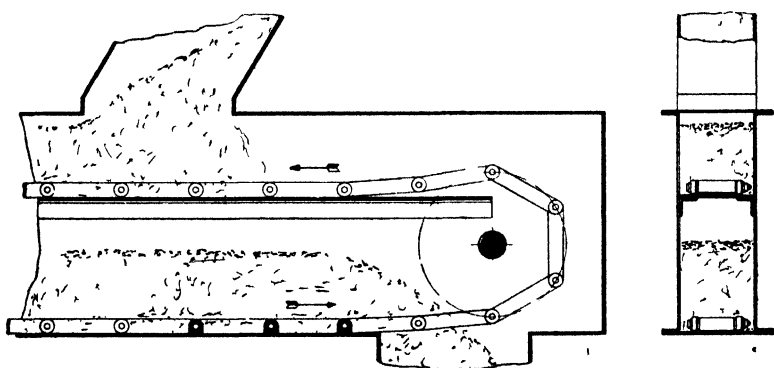


FIG. 15. DIAGRAM OF DRAG-LINK CONVEYOR

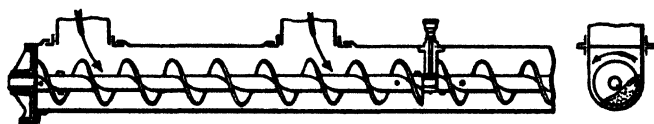


FIG. 16. SPIRAL CONVEYOR DIAGRAM

runs in two end bearings with the addition of a sufficient number of intermediate hanger bearings if the spiral is more than 10 ft. long. At the driving end of the conveyor bevel wheels are often fitted, or a chain drive may be used instead.

The close-bladed spiral where the flights touch the tubular shaft may be called a "continuous worm" conveyor; whereas the open spiral with ample "day-light" between is known as a "ribbon" conveyor. Both types of spiral are shown in Fig. 17. In an actual example the ribbon is 15 in. in diameter by 10 in. in

pitch having a section 3 in. by $\frac{3}{8}$ in., and is secured by brackets to a $2\frac{1}{2}$ -in. solid shaft.

The "ribbon" is less liable to choke up than the "worm" when handling damp and somewhat clinging

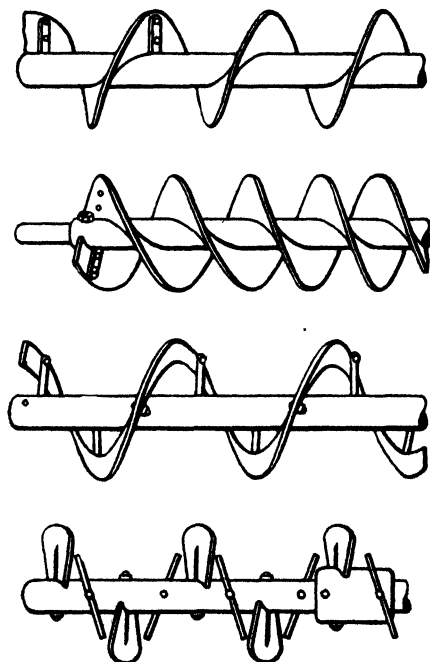


FIG. 17. VARIOUS TYPES OF SPIRALS

materials. It was first introduced into flour-mill practice about the year 1880, whereas the worm type is much older. The "paddle worm" type is another variant which is much used for sticky materials and for mixing purposes.

Both right-hand and left-hand spirals are regularly made, and sometimes double spirals, corresponding to a two-start worm, or even triple or three-start spirals. They are used on feeders for free-flowing materials.

Occasionally right- and left-hand spirals are combined on one shaft, thus enabling the same conveyor to feed material in opposite directions at the same time, and incidentally balancing the axial thrusts. For example, a bucket elevator erected near the middle of a range of overhead hoppers could conveniently supply coal to a right-hand spiral placed over one-half of the hoppers, as well as to a left-hand spiral serving the other half. This arrangement would simplify the driving gear.

The number of sizes of spiral conveyors regularly made is considerable, say from 4 in. to 24 in. diameter, though spirals bigger than 18 in. are unusual. When handling free-flowing materials such as grain and dry coal dust, the capacity of a ribbon or of a paddle-worm may be taken as some 20 per cent less than that of a close-bladed worm or continuous flight conveyor. This deduction, however, does not apply to sticky or clinging materials such as raw sugar or damp fine coal, where the ribbon and the paddle do better than the worm.

Speed, Capacity and Power. Practice varies as to the best ratio of pitch to diameter in spirals. American practice adopts equality as the standard ratio, whereas a ratio of from 0.5 to 0.75 is usual in British practice. The shorter its pitch the faster the screw will have to turn for a given capacity, but the steeper the inclination or slope up which it will be possible to convey the material. Short-pitch screws with a ratio of 0.5 are employed for pushing up inclines steeper than 20 degrees and for slow-speed feeders, as well as for vertical screws enclosed in pipe casings.

In Fig. 18 the upper curve or "graph" shows at a glance the working capacity, expressed in cubic feet per hour, of a wide range of spiral conveyors at the reasonable speeds (for coal) indicated by the straight

speed line. The pitch of each spiral has been taken as equal to its diameter here.

The lower curve translates the volume curve into British tons of 2240 lb., for medium-sized coal measuring 45 cub. ft. per ton. The values shown by the graph are tabulated overleaf, both for coal and for dry

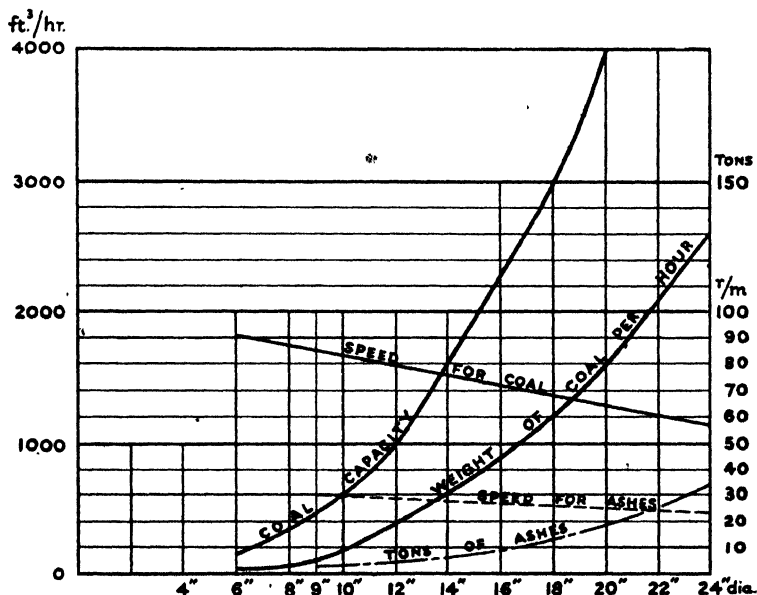


FIG. 18. SPEED AND CAPACITY CURVES FOR SPIRALS

ashes measuring 40 cub. ft. per ton, for which the speeds must be low, on account of the abrasive nature of the ashes resulting from the combustion of coal.

The next consideration is the *power* required to drive spirals, which is relatively high as compared with other types of conveyors in common use. For short conveyors, however, this is not an important

matter; and spirals are usually quite short, or below 50 ft. long.

Power is a function of torque and speed, the relation between the three quantities being

$$P = \frac{T \times R}{63,000}$$

where P is the horse-power transmitted by a shaft,

T pound-inches is the torque on the shaft,

and R revs. per minute is the speed of the shaft.

SPEEDS AND CAPACITIES OF SPIRAL CONVEYORS

Diam. of Spiral	Speed for Coal	Capacity		For Ashes	
		Volume	Weight	Speed	Weight
In.	Rev./Min.	Cb. ft./hour	Tons	Rev./min.	Tons
6	90	150	2.3	—	—
9	85	250	5	30	1.6
12	80	1000	20	29	4
14	75	1600	32	28	6.3
16	70	2300	46	27	9.6
18	67	3000	60	26	13.4
20	64	4000	80	25	19
24	55	6500	130	24	33

Hence, if the torque and the speed are known, it is easy to find the power absorbed. But it is not a simple matter to estimate the torque from a consideration of the length of a conveyor, its tonnage capacity, the friction of the load moving against the spiral and against the trough, as well as the running friction of the journal and thrust bearings.

Happily, the maximum working torque that can be safely put on the shaft is stated by some makers of spirals, and from this information one can calculate

the greatest safe power that can be transmitted by the shaft running at a given speed. The results of such calculations are tabulated below—

Diam. of Spiral	Safe Torque	Speed for Coal	Max. Power
In.	l.b.-in	r.p.m.	h.p.
6	3,060	90	4.4
9	3,060	85	4.1
12	7,600	80	9.6
14	9,270	75	11
16	16,400	70	18.3
18	16,400	67	17.5
20	25,600	64	26
24	25,600	55	23

Certain rather ponderous formulae have been proposed for calculating the power taken to drive a spiral, but they can only be applied with the aid of lengthy tables of variable coefficients, or numerical factors, suitable for different materials and conditions.

Even then there is no allowance for imperfect alignment of the trough and the shaft bearings nor for starting up the spiral when the trough is filled with material. So the safest plan is to base the power of the motor to be provided on the greatest safe torque that the shaft is good for, as stated in the above table.

For the sake of comparison and rapid checking, however, the power needed to drive a horizontal spiral may be roughly estimated by means of the following simple rule :

$$\begin{aligned} \text{Horse-power} &= \frac{F}{33,000} \times \left(\frac{\text{weight moved}}{\text{in pounds}} \right) \times \left(\frac{\text{distance}}{\text{per min.}} \right) \\ &= \frac{F}{33,000} \times (C \times W) \times L \end{aligned}$$

where F' is a factor depending on the nature of the load, say 1.3 for grain, 2.5 for coal, and 4 for ashes.

C' cubic feet per minute is the capacity of the spiral.

W lb. per cubic foot is the density of the material.

L feet is the length of the spiral.

Thus, for a 12-in. by 100 ft. spiral handling coal, the power needed to drive it will be

$$\frac{2.5}{33,000} \times \frac{1000}{60} \times 45 \times 100 = 5.7 \text{ h.p.}$$

This is for an output of 20 tons of coal per hour at a speed of 80 revolutions per minute, as per the table on page 260. The bearings are assumed to be either whitemetal or bronze. At higher speeds the power will go up in proportion.

In the same way we get 17 h.p. for an 18-in. spiral of 60 tons per hour capacity, which is within the allowable torque. This is not so, however, in the case of a 24-in. by 100 ft. spiral having an hourly capacity of 6500 cub. ft. or 130 tons of coal, when running at 55 revs. per minute, because the estimated power required to drive it becomes

$$\frac{2.5}{33,000} \times \frac{6500}{60} \times 45 \times 100 = 37 \text{ h.p.}$$

whereas the limiting value based on the safe torque on the shaft is only 23 h.p.

Hence 100 ft. is too long for a standard spiral 24 in. diameter. The length should be reduced to $\frac{23}{37}$ of 100 ft. or 62 ft. In practice spirals handling coal are seldom as long as 60 ft.

The above power rule may be simplified still further, for spirals handling heavy materials, by choosing a

numerical factor of 3.3, instead of 2.5, and a definite length of 100 ft. The estimated power then becomes

$$\frac{3.3 \times 100}{33,000} \times \left(\frac{\text{weight of material moved per min. expressed in pounds}}{\text{number of pounds per minute}} \right) = \frac{\quad}{100}$$

This rule is the acme of simplicity, and it gives a safe margin of power for contingencies. In the case of a 12-in. coal conveyor, for instance, it gives 7.5 h.p. for the driving motor, while the maximum torque power is 9.6, according to the table. For lengths other than 100 ft. the power absorbed is nearly proportional to the length of the conveyor.

This is near enough for a *horizontal* conveyor; but if the conveyor is inclined, the additional power expended against gravity in lifting the load a certain height per minute must be calculated separately and added to the frictional horse-power. Similarly for all types of inclined conveyors.

COMPARISON OF CONVEYOR TYPES

To a considerable extent the modern drag-link or "Redler" type of conveyor has superseded the older spiral type, save for short feeding and mixing conveyors. For spirals one may take 100 ft. as the useful limit of length, apart from grain conveyors and similar applications, unless driven at both ends.

Yet compactness and ease of installation are attractive features of both types of conveyor, which can be conveniently supported and erected either horizontally or set at a considerable inclination. Indeed, spirals can be run vertically, if enclosed in a suitable pipe casing. So also can certain forms of "Redler" chain conveyors, as indicated in Fig. 19.

But both spirals and "Redlers" are more suitable

for conveying powdery and granular substances than lumpy materials. For handling ashes and clinker, however, a special heavy worm conveyor is available, built up of cast-iron flights or segments on either a square or a round shaft.

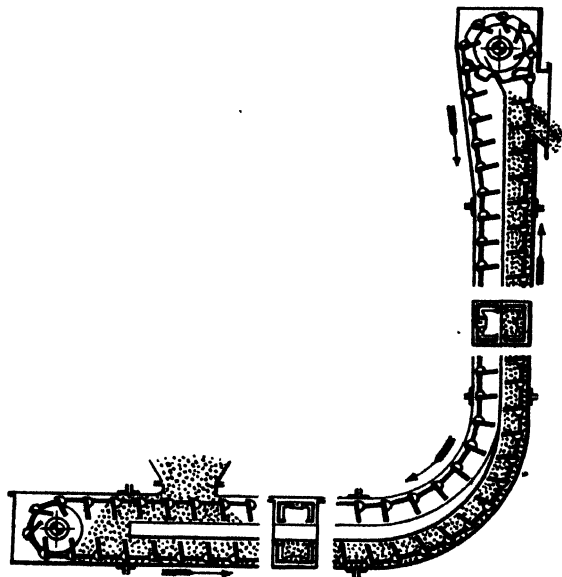


FIG. 19. "REDLER" CONVEYOR-ELEVATOR

When examining spiral, drag-link (Redler), and push-plate conveyors critically, we note that they all possess one feature in common, viz. a *trough* or channel along which the coal or other material is propelled. One may compare the propelling device with a ship's screw propeller, in the case of a spiral or screw conveyor, and with a ship's paddle, in the case of a push-plate conveyor. The floats of a paddle-wheel correspond in function to the push-plates or flights of a conveyor, which push the coal along the trough to its destination.

By way of contrast we further observe that the troughs of "spirals" and of "Redlers" are always deep and closed by a cover, whereas the troughs of "scrapers" are comparatively shallow and always left open.

Furthermore, each of these conveyors is of the multiple-discharge type, i.e. there are several openings in the bottom of the trough fitted with sliding doors or "gates," through which the coal is discharged as required. Thus these outlet doors provide the simplest possible means of securing a pre-selected delivery of the material conveyed, a feature of considerable importance in conveyors. Some other types of conveyors can deliver material at one point only, a drawback which limits their application.

(g) HANDLING ASHES AND FOUNDRY WASTE

The transport of ashes and clinker from boilers, gas producers, and metallurgical furnaces is a rather troublesome matter, on account of their abrasive and destructive properties. Yet many ways of dealing with them are available, whether they are dry and dusty or in the wet and corrosive state.

One method is to wheel the ashes in iron barrows or in electric battery trucks to a convenient spot in the yard, and there tip the contents into the boot of an inclined continuous-bucket elevator, which then lifts the ashes into an overhead bin, or storage hopper, fixed high enough to allow a motor lorry, equipped with a tipping body, to run under it, as shown in Fig. 20. The bin may be built up of cast-iron plates bolted together or of ferro-concrete. Steel plates are hardly sufficiently durable for this duty, as they corrode so soon in an exposed position.

By operating a suitable discharge valve, or outlet gate, at the bottom of the bin, a 5-ton lorry can be loaded up in a few minutes. It will then proceed to discharge its load at the nearest public or private tip, the body of the lorry being rapidly tipped either by

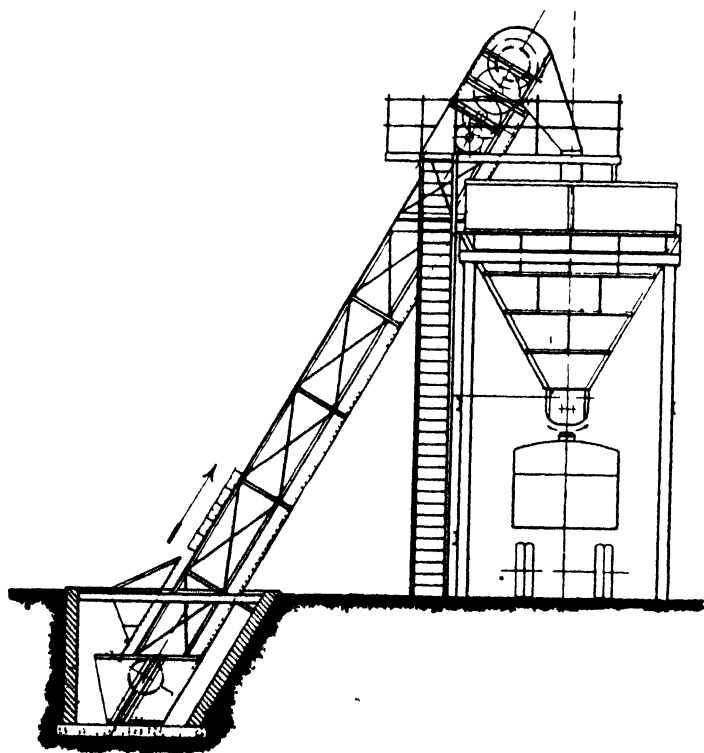


FIG. 20. CONTINUOUS ELEVATOR FOR ASHES

power or by hand screw gear. This method of disposal is equally useful in foundries and steelworks, where large quantities of spent sand, furnace clinker, slag and fused firebricks have to be got rid of daily, as an inconvenient by-product of the works.

In mining districts a wire ropeway is frequently utilized for taking works and colliery refuse to a spoil heap or dump situated a considerable distance away. This economical method is much employed for the disposal of refuse from South African gold mines, the neighbourhood of Johannesburg having many prominent spoil banks.

Fig. 21 illustrates a little bucket elevator, with curved lattice frame, designed for raising and delivering small ashes into a narrow gauge truck at a steelworks. There should be a feed grid over the boot, so as to keep back any pieces of clinker too big for the buckets to accommodate. The wear on the buckets and chain of such an elevator is necessarily heavy. To relieve the wear on the top guide at the bend, a supporting roller is fitted there below the chain. All elevators and conveyors handling ashes should be run at a slow speed, otherwise their life will be short.

A simple *skip hoist*, as shown in Fig. 22, is a useful alternative to a bucket elevator for ashes. Instead of a series of small overlapping buckets bolted to an endless chain, this has a single large bucket or "skip," having a capacity of 10 cub. ft. or more. The skip carries four little flanged wheels, which run on two tracks diverging at the top, so that when the skip is in its highest position it is automatically tipped.

The skip is filled from a small bottom hopper, which receives the ashes from iron barrows. The hoisting gear is then operated by a control lever, which at once puts into contact the friction wheels of the power-driven hoisting crab, and so the loaded skip climbs upwards. A safety rope connects a rocking lever at the top of the hoist with the shorter arm of the control lever on the crab.

At the point of discharge the skip automatically throws out of gear the friction wheels by means of the

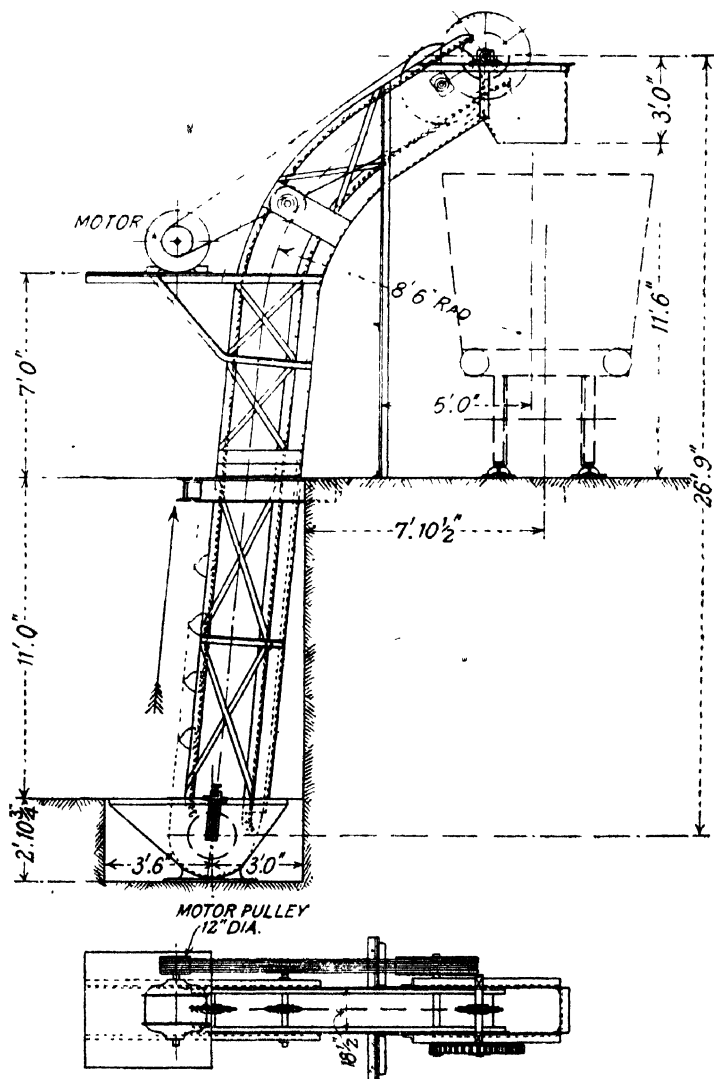


FIG. 21. SMALL CURVED ELEVATOR FOR ASHES

safety rope, thus preventing over-winding. Then the skip is held securely in its tipping position by the large friction wheel being dropped into contact with the fixed brake block.

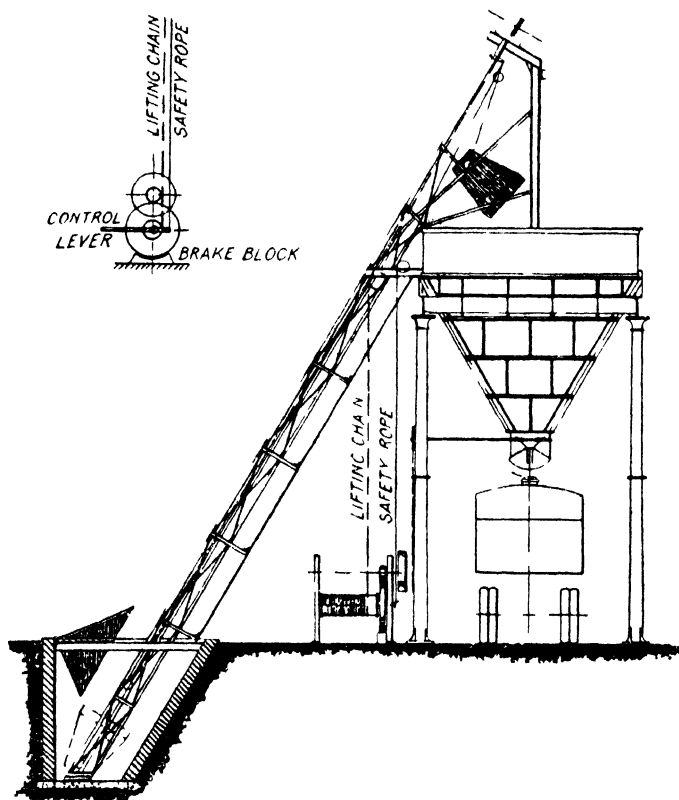


FIG. 22. SIMPLE SKIP HOIST FOR ASHES

During the fall of the skip by its own weight for reloading, the control lever is held by hand in mid-position, when the friction wheel runs clear of both pinion and brake block. As the skip nears the bottom

its speed is checked by releasing the control lever, thus putting the friction brake in gear.

Either hot or cold ashes and clinker can be raised by a skip hoist, and a point in its favour is that the lifting chain is not exposed to the destructive action of the ashes. It is advisable to limit the size of the clinker; otherwise the excessively large lumps would jamb, or block up, the outlet from the overhead bin, thus necessitating some labour with a bar to release them.

Twin skip-hoists are also made, so designed that an empty skip falls whilst a full skip is being raised, so that only the *net* load is unbalanced. The first cost of such a twin skip-hoist, however, is considerably higher than that of a simple hoist with only one skip.

In the absence of an overhead storage bin, one can apply a *mechanical shovel*, mounted on a Fordson petrol tractor. Such a shovel forms a very convenient means of loading ashes and clinker into motor lorries from a heap either in the open yard or inside a building. This is a remarkably mobile and valuable labour-saving machine to have available in a foundry yard. It is described at some length on a later page. (See Fig. 45.)

The application of an overlapping tipping-bucket conveyor-elevator to the duty of raising both coal and ashes up to storage bins serving a boiler-house is indicated in Fig. 23. Although this method has been carried out in a number of cases, yet it is better practice to separate the handling of ashes entirely from the handling of coal. Here the horizontal transport of coal within the boiler-house is effected by small trucks, which also remove ashes from the boilers to the grid over the feed chute to the conveyor.

Space does not permit of more than a passing reference here to *suction* ash-handling plant. The air suction principle was first applied some thirty years ago to

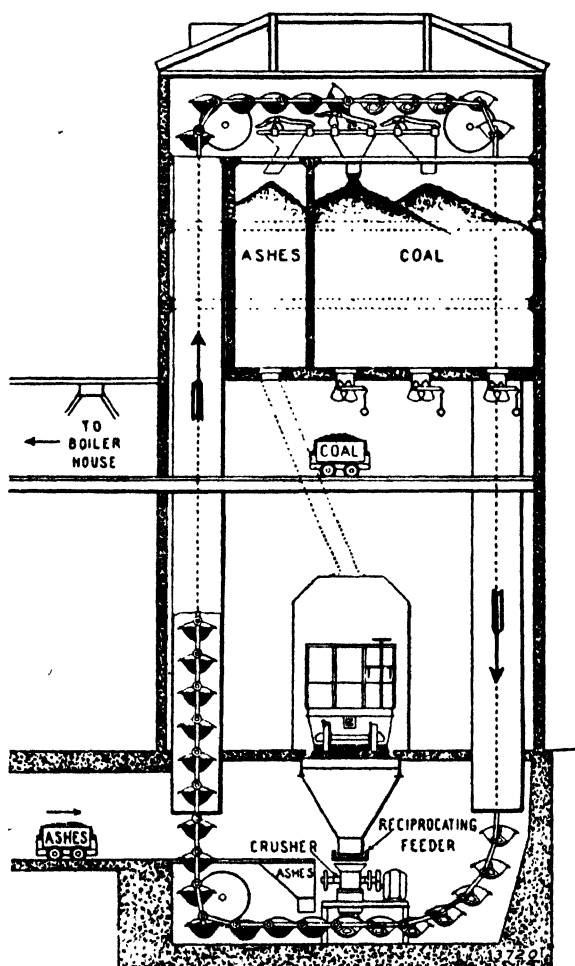


FIG. 23. TIPPING-BUCKET CONVEYOR

the conveyance in pipes of ashes and small clinker from boiler-houses, though it had been utilized some fifteen years previously for unloading grain from ships and barges.

This pneumatic method is certainly convenient for collecting ashes from various points into one central storage bin, with a minimum of labour and dust; but it is very wasteful of power, while the wear on the pipe bends is severe. Hence the bends should be of large radius and be fitted with renewable liners.

A suction plant comprises a rotary exhaustor connected by a system of pipes to an elevated receiver, or vacuum tank, fitted with an air lock. The exhaustor creates a partial vacuum in the pipes, and the superior external atmospheric pressure then forces the ashes through the suction nozzles and pipes into the receiver.

In boiler-houses where there is no underground ash cellar for conveniently accommodating a breaker, it is usual to fix a *grid* near the boilers, over the receiving box in the suction ash pipe. On this *grid* any big lumps of clinker have then to be broken up by hand.

(h) **BELT CONVEYORS**

In large modern power-houses belt (or band) conveyors are extensively used for handling both coal and ashes. For big capacities and great lengths they are more suitable than any other type of conveyor, provided space permits of their use. They are quiet-running and economical in power consumption, but the inclination should be below 20 degrees. As the angle increases the capacity falls off.

Commonly a rubber-covered canvas belt, from 4- to 8-ply thick, runs over a pair of wide pulleys (or end drums), and is supported at intervals of about 4 ft. by a large number of troughing rollers, styled "idlers," which form the belt into a continuous shallow trough and thus double its carrying capacity. The return run of belt is supported by plain idlers set some 10 ft. apart. The idler bearings are either plain and grease lubricated, or of the ball or roller type. A short slow-

speed belt, however, may occasionally run in a steel or a wooden trough.

Trippers. When equipped with a movable tripper (or throw-off carriage), as outlined in Fig. 24, a belt conveyor can discharge coal at any point required over a long range of hoppers. Such a tripper may be

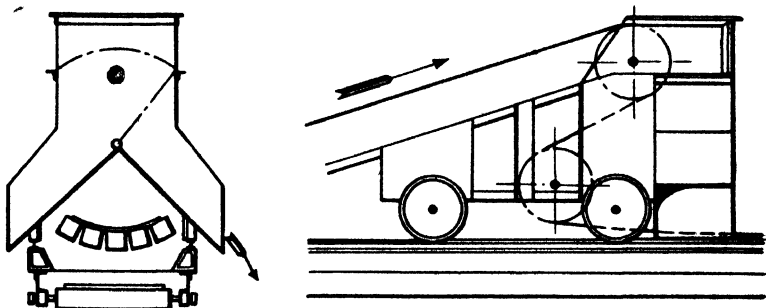


FIG. 24. MOVABLE TRIPPER

clipped to the rails at one spot for a time, until that part of the hopper has been filled, and then moved on to another spot for similar filling. Or a travelling tripper may be arranged to be always on the move, traversing the full length of a range of hoppers and then reversing automatically, so as to fill the hoppers uniformly, with hardly any attention being required.

Moreover a tripper can be arranged with symmetrical chutes so that the coal can be discharged equally on both sides of the belt; or else returned to the belt occasionally, when one desires to pass coal over the end of the conveyor or to other trippers on a long conveyor. The special design of reversible throw-off carriage shown in Fig. 25 permits of discharge from a belt when running in either direction. This is necessary when coal is fed to the conveyor from an elevator placed near the middle of the conveyor instead of at one end.

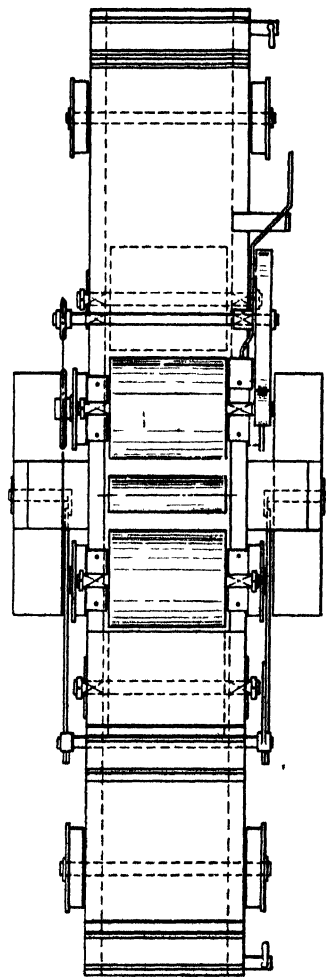
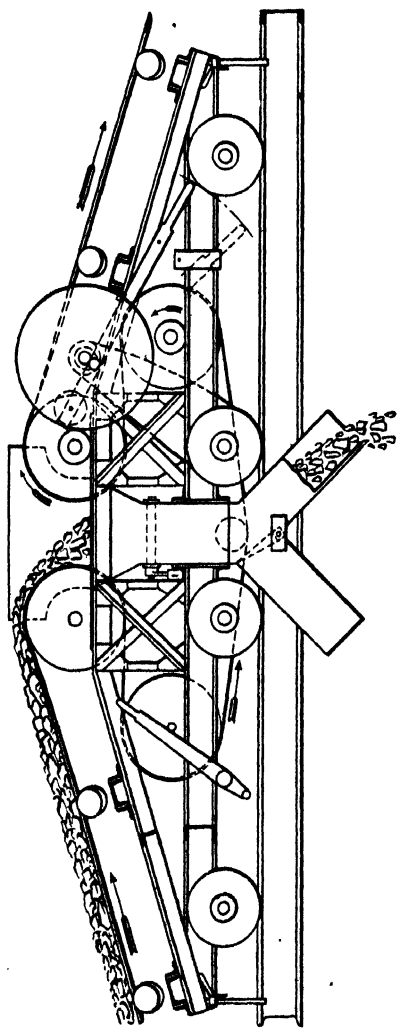


FIG. 25. REVERSIBLE TYPE OF TRIPPER

Alternatives to trippers are several hinged ploughs fixed at intervals, or one travelling plough for pushing the coal off the belt. Ploughs are sometimes more convenient to apply than trippers, as they need less headroom. They are also cheaper than travelling

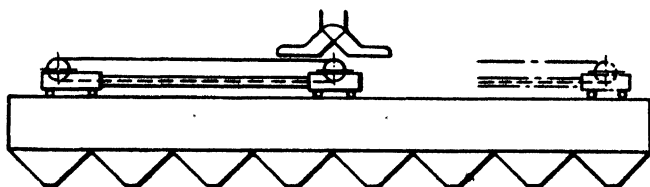


FIG. 26. DIAGRAM OF SHUTTLE BELT CONVEYOR

throw-off carriages, but are apt to cause more wear on the belt.

A further alternative is the use of a short slowly travelling and reversible shuttle-belt conveyor discharging coal from each end alternately into overhead storage bins (see Fig. 26). This type of machine is favoured in some boiler-houses and the retort-houses of gasworks, since it produces a fairly uniform mixture of different cargoes of coal.

Supporting Rollers. The special pulleys (of some 5 in. diameter) used for supporting the loaded belt are variously styled idlers, carriers, rollers and rolls. The return run of belt is always supported by plain rollers of small diameter, often 4 in., now usually a single piece of tubing, but formerly made up of several short units fixed to one spindle.

The carrying idlers are now generally built up of three equal rolls, thus avoiding the needless complication of using 5-roll idlers, with their multiplicity of bearings, which were formerly in vogue for supporting wide belts and are still sometimes used. The rolls should be turned or ground true on the outside.

Long conveyors are preferably fitted with anti-friction bearings (ball or roller), both taper and Hyatt rollers being used successfully on this service. Fig. 27 shows a plain roll fitted with a grease cup on one side of the belt and a ball-bearing roll with a grease-gun nipple on the other side, as a modern alternative.

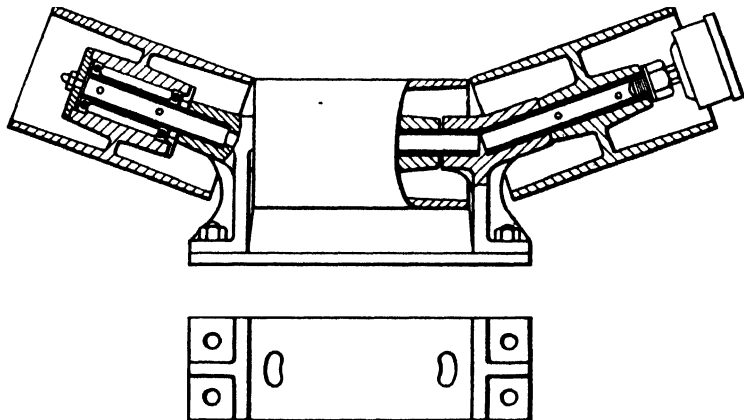


FIG. 27. TROUGHED BELT IDLER

The troughing angle is now often 20 degrees, more rarely 30 degrees; though in the past belts have suffered angles up to 45 degrees, and died early in consequence! Steep troughing idlers still survive, however, in the case of wide slow-speed picking belts at collieries and mines; these travel at 40 ft. per min., instead of the usual 200 to 400 ft. per min. of normal belts handling coal in boiler-houses.

Side guide rollers are less needed than formerly, when deep troughing was in vogue, though a few are sometimes provided for narrow belts. They should not be used to force the belt straight, however, but only as a safeguard against accidental loss of alignment. Slots in the base of idler brackets permit of sufficient adjustment to train the belt to run straight.

Size of Pulleys. As regards the proper size of conveyor belt pulleys (or drums) it is very important for the life of the belt not to make them too small; a defect that causes the multiple plies of the belt to come apart prematurely. One is tempted to cut down the size unduly, in order to reduce the initial cost of the conveyor. A minimum diameter for an 18-in. belt is 21 in., and for a 36-in. belt say 30 in. But the governing factor is really the thickness of the belt, which mainly determines its flexibility, the lack of which would prevent the belt from wrapping freely around the pulleys.

A good rule is to make the diameter in inches of all "head" (or driving) pulleys at least five times (better six) the number of plies (or layers of cotton duck), and the "tail" pulleys at least four times the number of plies. Thus a 6-ply belt would have a 30-in. head pulley and a 24-in. tail pulley at least. When a "snub" pulley is used to increase the arc of contact of a belt on the head pulley from, say, 180 degrees to 240 degrees for heavy duty, its diameter may well be 18 in. at least.

Moreover the face of pulleys should be 2 or 3 inches wider than the belt, or even more in the case of belts over 36 in. wide. In order to centre the belt the pulleys must be rounded or "crowned" on the face, to the extent of, say, $\frac{1}{8}$ in. per foot of width; though this crowning is less important for wide than for narrow belts.

Steel Belts. In the case of thin steel belts, as originally manufactured at Sandvik, in Sweden, the end pulleys are made not wider, but a few inches narrower than the width of the belt. Though plain flat cast-iron pulleys are commonly used, yet wood lagging is sometimes added to the head or driving pulley. This should be made at least 40 in. in diameter, in order to ensure

the satisfactory life of a high-tensile steel belt little more than $\frac{1}{8}$ in. thick.

Steel belts have found useful application in sugar refineries, also for handling clay and moulding sand, as well as sand cores in the core shops of engineering foundries. A point in their favour for certain duties is the ease with which material may be pushed off the belt sideways by means of a diagonal plough, either fixed or movable. In fact ploughs can be arranged to discharge simultaneously at several places.

Other Belts. Solid-woven cotton belts for light duty are very flexible and will bend round pulleys of relatively small diameter. They are apt to stretch much more than rubber-canvas belts, and are not utilized for heavy service, being most commonly employed on small package conveyors.

Belts made of balata (a tree-gum resembling rubber) are also used to a limited extent. Balata-canvas belts are much stiffer than rubber-canvas belts of like thickness, and therefore demand bigger pulleys and shallower troughing.

Steel wire belts are employed to some extent for handling bags and boxes, though less so than formerly, having been largely displaced by chains and slat conveyors. For some special applications (such as continuous drying ovens), there are also in use woven wire belts supported by a pair of side chains running over sprocket wheels.

Capacity of Belt. The carrying capacity of a belt conveyor varies as the width of the belt squared, or nearly so, and directly as the speed. It is assumed that other things are constant, such as the size and density of the material conveyed, the regularity of feeding, the degree of troughing, and the inclination of the belt.

A simple rule for capacity is to square the width of the belt in inches and multiply by 3. This gives

roughly in cubic feet the belt's capacity at a speed of 100 ft. per min. To get the *tonnage* capacity, multiply by the actual speed ratio and divide by the number of cubic feet per ton in the material carried.

For a 24-in. horizontal belt, running at 200 ft. per min. and handling bituminous coal measuring 45 cub. ft. per ton, this rule gives—

$$\left(24^2 \times 3\right) \times \frac{200}{100} \times \frac{1}{45} = 77 \text{ tons per hour}$$

This assumes regular feeding and a fully-loaded belt.

Power to Drive. As regards the power required to drive an inclined belt conveyor, it is best to calculate the various items separately in each case and then add them up. These items include—

- (1) The power needed to drive the empty conveyor.
- (2) The power needed to convey the load horizontally.
- (3) The power taken to lift the load upwards.

The first two items are much influenced by the type of idlers used. For a first approximation, however, a convenient rule applying to a conveyor fitted with ordinary grease-lubricated idlers is the following—

$$\text{Horse-power at head shaft} = \left(\frac{0.02 L}{100} + \frac{0.01 H}{10} \right) T$$

where L ft. is the length of conveyor between end pulleys,

H ft. is the lift, and T tons is the load capacity per hour.

This formula can be simplified to read—

$$\left(\frac{1}{5} L + H \right) \frac{T}{1000}$$

Thus the power absorbed by the above 24 in. coal conveyor, of 400 ft. centres and 20 ft. lift, handling 77 tons of coal per hour, would be—

$$\left(\frac{1}{5} \times 400 + 20 \right) \frac{77}{1000} = 7.7 \text{ h.p.}$$

Clearly the power needed to drive a belt conveyor of moderate capacity and length is quite small at the head shaft. Of course some allowance is necessary for transmission losses. If we assume that the combined efficiency of the transmission gears is 0.7, then the brake horse-power of the driving motor will be $7.7 \div 0.7$ or 11. Yet the starting load on the motor would be rather more than 11 horse-power, on account of the inertia of the mass to be set in motion. Hence the motor should be capable of exerting a considerable excess of starting torque.

(i) **MONORAIL CHAIN CONVEYORS**

Of recent years much progress has been made in the application of overhead trolley conveyors to engineering shops, especially those engaged in the motor car industry, where they are largely utilized both in foundries and machine shops. Yet they are less suitable for moving bulk materials than for handling a constant stream of isolated articles, or goods enclosed in containers, which are placed on suspended carriers spaced a few feet apart.

Great flexibility is perhaps the most remarkable feature of this type of conveyor, especially when equipped with biflex or bi-planer chains, for these permit of motion in two planes at right angles to one another. Thus both horizontal and vertical bends can be negotiated without difficulty.

Although some of these single-chain trolley conveyors are of great length and complexity, others are quite short and simple, as in the case of shell conveyors passing straight through drying ovens. They need little supporting framing, as they can usually be partly hung from existing roof principals. Hence they occupy a minimum of floor space and are inexpensive.

Fig. 28 shows one form of trolley for supporting a

carrier beneath it. It runs on a steel joist track, being pulled along by a Vale biflex chain. This is an ingenious modification of an ordinary Ewart pinless chain, adapted to articulate in two planes, and thus enabling the chain to be led around corners of buildings, and also over doorways and other obstacles that tend to impede the free lay-out of a conveyor.

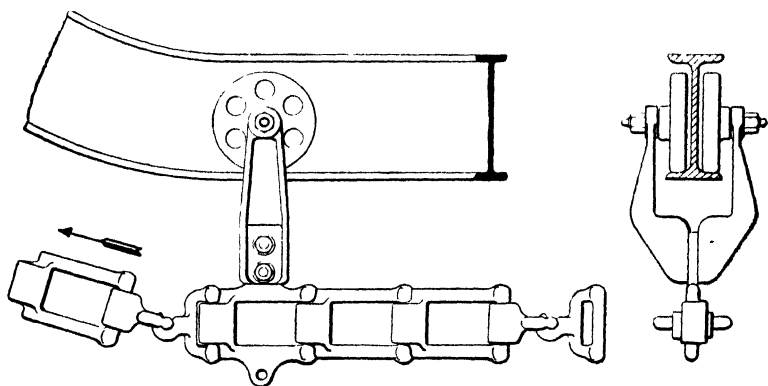


FIG. 28. "VALE" BIFLEX CHAIN AND TROLLEY

For heavier work another type of chain (Fig. 29) is much used. This has malleable iron centre links and flat steel side links, and is therefore styled "combination chain." In order to make it sufficiently flexible for tracks having sharp bends and dips, one has to introduce at intervals swivels, or universal joints, as indicated. The load hanger shown is designed to suit a track of at least 6 ft. radius and a maximum angle of 45 degrees with a trolley-spacing of twelve chain pitches, or say 31 in.

This combination chain is employed in the so-called "pendulum" type of mould conveyor drawn in Fig. 30, as erected at the Dagenham foundry of the Ford Motor Co. Ltd., where there are several such conveyors, each

of about 620 ft. circuit. It will be noticed that the carriers, or pendulums, are slung from four-wheel trolleys, a perforated table to accommodate the moulding boxes being interposed between each pair. Chain

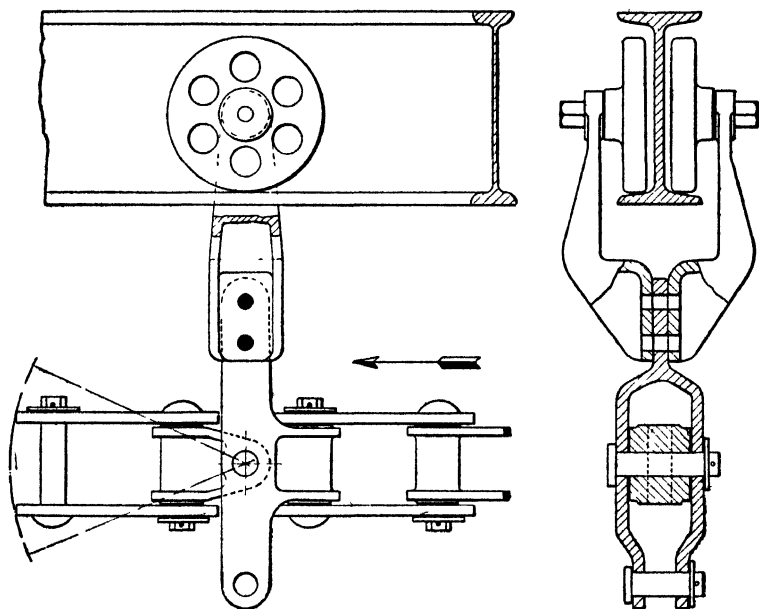


FIG. 29. COMBINATION CHAIN AND TROLLEY

speeds here range from 10 ft. per min. upwards. Some carriers of this general type have four or more decks per carrier, adapted to receive numerous sand cores passing slowly through drying stoves, or baking ovens.

Fig. 31 is a perspective view of a Renold biplaner steel chain, which is suitable for overhead trolley conveyors with many turns and slopes.

(k) SHELL HANDLING

A simple form of belt conveyor for temporary service is indicated in Fig. 32. It has been used successfully

to convey shells up to 6 in. size a distance of 40 ft. at slight expense. A wood trough guides the shells,

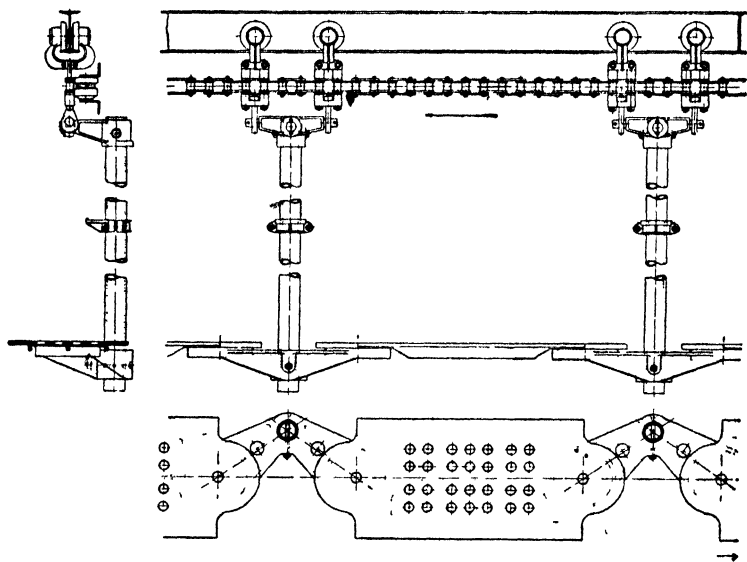


FIG. 30. CARRIER FOR MOULD CONVEYOR

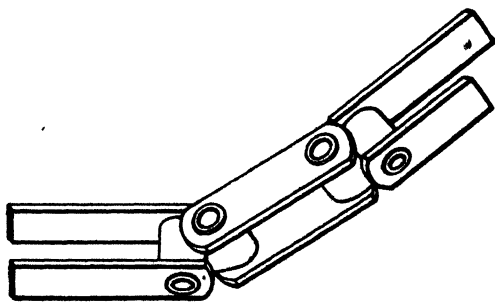


FIG. 31. "RENOLD" BIPLANER CHAIN

and a sliding belt carries them safely along, until they are pushed off by a fixed plough on to a receiving table.

The folding inset (Fig. 33) represents an effective conveyor erected at a Sheffield steelworks, for the

purpose of taking shell *forgings*, in sizes ranging from 4 in. to 7 in. diameter, over a roadway 20 ft. wide and delivering them down a hinged chute into a railway wagon standing on the other side of the roadway.

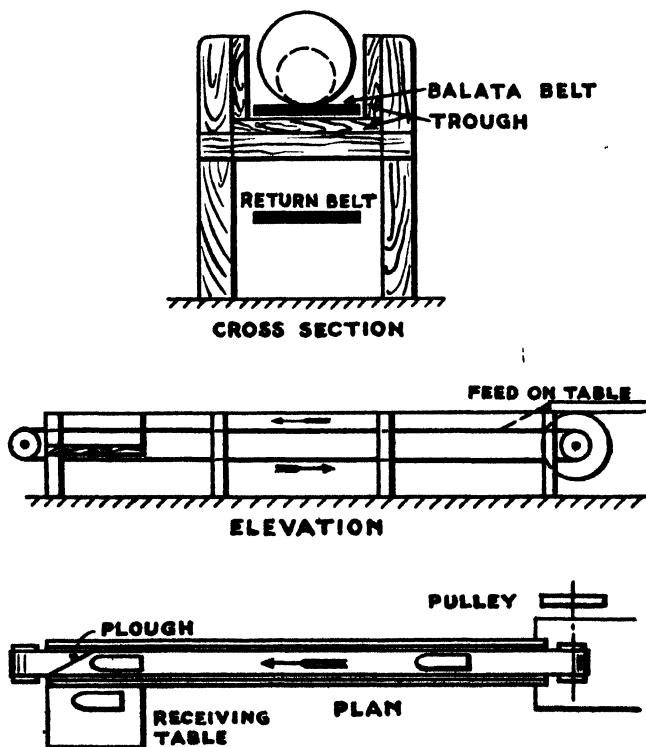
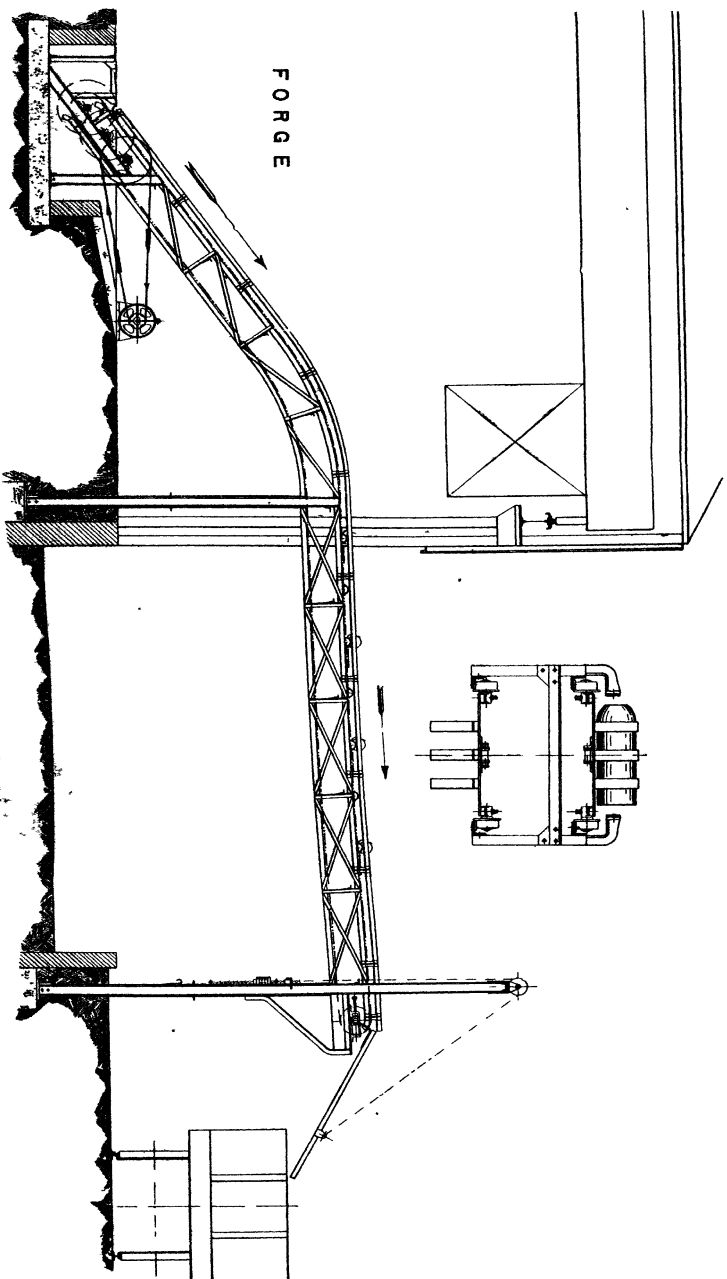


FIG. 32. SIMPLE SLIDING BELT CONVEYOR

A minimum headroom of 11 ft. 6 in. had to be maintained, for the passage of motor lorries along the roadway. The enormous saving of time and labour thus effected is obvious.

The length of this conveyor between centres is 48 ft., and the carriers are pitched 5 ft. apart, thus giving



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FIG. 38. CHAIN CONVEYOR FOR STEEL FORGINGS

a carrying capacity of nine shell forgings per minute, or 540 per hour, with a chain speed of only 45 ft. per min. The carriers are composed of steel slats with curved arms riveted on and having flanged rollers of 4 in. diameter, running on an inclined track supported by lattice steel framing. They are dragged along by a single chain of 6 in. pitch, engaging with sprocket wheels of 18 in. diameter.

The curved arms on the carriers, resembling a three-pronged fork, mesh with loading fingers fixed at the floor level of the forge, thus enabling a forging to be rolled into position as soon as cold enough and picked up automatically without any exertion.

In this case the conveyor is driven at the lower end by a small electric motor of only 3 h.p. through a belt and double-reduction gearing. The delivery chute is hinged from the end shaft and controlled by two chains, running over guide sheaves and fitted with balance weights, suitable stops being arranged.

To elevate round steel bars and shells the type of machine illustrated in Fig. 34 may be employed. This particular elevator was erected in an engineering works to raise from a basement store into a machine shop above it numerous round bars of 3 in. diameter in lengths ranging from 3 to 12 ft. A neat artifice is the method of delivering the bars automatically from the rising chains by the use of deflecting wheels arranged so as to cant the carriers sufficiently for the bars to roll off on to the delivery table. The same principle has been applied recently to small shell elevators, both fixed and portable.

(1) MECHANICAL HANDLING IN A MOTOR CAR FACTORY

As typical of a large modern motor car works one may instance that of Morris Motors, Ltd., at Cowley,

Oxford, where the assembly shop under one roof is half a mile long and where ten miles of travelling

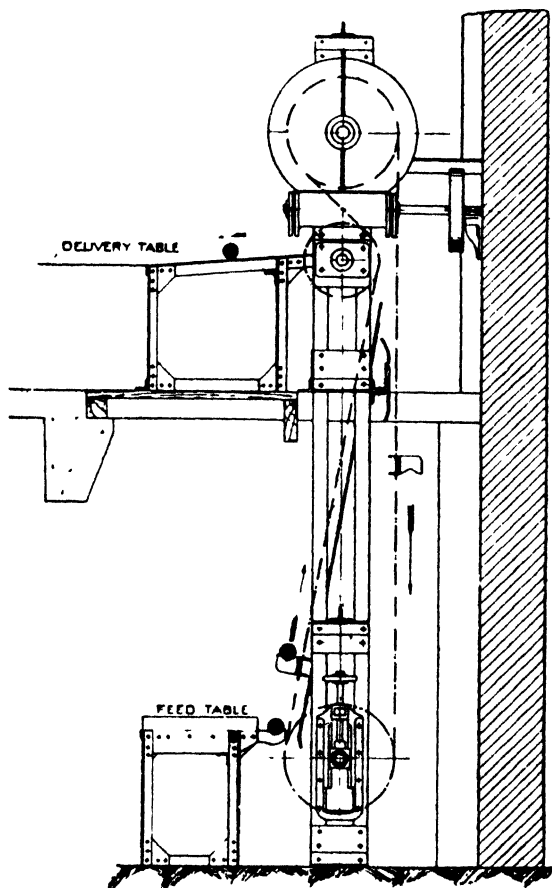


FIG. 34. TWIN-CHAIN BAR OR SHELL ELEVATOR

chains are used to move along the cars and their component parts. One of the conveyors is no less than three-quarters of a mile long around the entire circuit.

These works have a productive capacity of 100,000 cars a year and the metals used in their construction

amount to 70,000 tons, according to a descriptive account given to the author when he visited the Morris works.

Yet this huge factory is mainly an assembly plant to which many of the finished parts of a car converge. Indeed not much actual manufacturing takes place there. The Cowley works are in fact fed by a number of "specialist" factories, each of which gives undivided attention to the manufacture of a fraction of a finished motor car as it appears on the road.

Thus a large foundry in Coventry, forming part of the Morris organization, produces the grey iron castings used in these cars, while the malleable iron castings are purchased from outside sources. Another factory at Coventry concentrates on the production of finished engines and gear-box units, while yet another devotes its energies and plant exclusively to the construction of motor bodies. Lastly, a separate factory at Oxford makes nothing but radiators.

In traversing the different departments of the Cowley works one notices that various outside components are received in the appropriate stores, where they are inspected, both as to quality and sizes, before being placed in the store bins and racks. The parts are fed to several sub-assembly lines, or to the main assembly line, by a system of chain conveyors, mostly of the overhead monorail type, having a large number of little trolleys pulled steadily along a steel joist by an endless chain driven by an electric motor.

The course taken by a few selected details will be followed throughout the plant. The "back axle," for example, is lifted from the axle sub-assembly line by an electric trolley hoist running on an overhead joist, and transferred to the spray-painting booth.

Here the axles are sprayed with a black preservative as they are slung from an overhead conveyor, and then

slowly conveyed through a drying stove, whence they emerge protected by a hard weather-proof finish. Some other components (such as petrol tanks) are also fed to the axle conveyor, whilst slowly travelling, on which they are treated with petrol-proof black lacquer, as they pass through the spray booth.

After leaving the drying stove or oven the axles go into the finished axle store, each car model having its own storage rack. From this store the axles are fed on to a long conveyor that delivers them to the chassis assembly conveyor, which is situated in the main assembly shop.

It would be tedious to follow through the plant all the details of a car, but the course of a few more items may be traced with advantage.

The sheet-metal "wings" or "mudguards" of cars, also the luggage "carriers," on entering the works are fed by a band conveyor to the stove enamelling plant. Here these light parts are loaded on to a double-strand chain conveyer, which takes them through a hot degreasing bath, a hot water washing spray, and a drying oven in succession. Then they go through an enamelling bath and finally enter a high temperature continuous oven, which bakes the enamel to a hard black finish.

In a similar way the car wheels are dealt with in a smaller oven; after which both the wings and the wheels are inspected and passed forward on a chain conveyor to the assembly line.

The pressed steel chassis side-frames, as received from outside steelworks, are transferred to the frame store by the aid of two light overhead travellers, each serving six store lines. These travellers also carry the frames as required to the drilling fixtures, where holes are drilled for the engine bolts, etc. After being inspected as to the size and location of all holes, the

finished frames are conveyed to the chassis assembly line.

As regards the car engines, these are delivered complete from the Morris engine works at Coventry, already tested and run in. They are stored in racks, each engine being mounted on a little four-wheeled trolley in order to facilitate handling. An elevator takes the engines from the racks to the sub-assembly lines on a gantry, where the small accessories are fitted in place. The entire engine is then picked up by a suitable hoist and lowered through an opening in the gantry floor into position on the chassis frame below.

In this manner the chassis rapidly grows into a car as each component is fitted to the frames, whilst slowly moving along on the assembly conveyor. The engine, the back axle, and the propeller shaft are lowered simultaneously from the gantry above. Five assembly lines are fed continuously with the necessary parts from a central gantry served by a conveyor which brings from the stores the appropriate supplies in standard containers.

The wheel tyres are delivered by the makers direct to the tyre store, close to the enamelling plant already mentioned. They are put on the wheels by expert tyre fitters, then inflated and fed on to the wheel conveyor. This ingenious machine delivers wheels of different sizes automatically to the correct assembly line, being provided with a "pre-selective" device.

After close inspection, the finished chassis (still minus its body) is traversed to one of a pair of conveyors, which takes it to the body-mounting shop. A third conveyor, running parallel to the others, delivers trimmed bodies to the body-mounting line, from the end of which the body is picked up by an overhead hoist and placed on its chassis.

As the car travels through the mounting shop on

the assembly conveyor the body is bolted to the chassis. Then the seat boards, the floor boards, and the dust excluders are fitted, as well as the wind-screen wipers, the sun visors, and the number-plates. By the time the car reaches the end of the assembly line the seats and the "bonnet" have been put in position, the car then being ready to go to the testing department for final inspection, adjustment, and a test run on the road.

In some other motor car works which have been visited by the author (including those of the Austin, the Ford, and the Vauxhall cars), the assembly operations are very similar to the above, but more actual manufacturing of the mechanical details is done under one roof, the different factories being centralized. Body-building is, of course, a large business in itself. Some well-known firms, such as Rolls-Royce Ltd., do not make motor bodies at all.

The Dagenham works of the Ford Motor Co., Ltd., include a foundry 1300 ft. long by 300 ft. wide, as well as a blast furnace for making pig iron and a range of coke ovens for making furnace coke. Serving the machine shop is an overhead endless chain conveyor no less than two miles long, and forming a travelling store of material, which is thus brought directly to the hands of the workman, who does not need to move away from his lathe or other tool. Thus conveyors have to perform at least three functions, viz. to transport, to store, and to set the pace or regulate the rate of production. It needs much planning to utilize conveyors to the greatest advantage.

(m) **MECHANICAL HANDLING IN A MODERN FORGE**

So much for the process of assembling motor cars on a big scale in mass-production factories. It will

now be instructive to consider the lay-out of the forging and heat-treating departments of one large American motor car works, with the aid of a diagram (Fig. 35) prepared from information supplied by the Willys-Overland Co., of Toledo, Ohio.

This new lay-out of a forge shop took the place of an old plant on the same site. Its substitution had the pleasing effect of cutting down by some two-thirds the former cost of material-handling in this department. Here the system of "routing" the work has been given close attention, in order to save useless labour and reduce the cost of internal transport by the aid of straight-line production, thus ensuring the shortest possible route taken by the work in progress.

To realize the meaning of this it will be best to trace the course of operations performed on a few typical details in their passage through the shop from start to finish. It should be noted that the big machine shop comes just below the picture.

Referring to Fig. 35, we notice at the top left-hand corner the access railway tracks and the two open steel storage yards, each of the latter being served by a $7\frac{1}{2}$ -ton overhead travelling crane of 67 ft. span, which transfers the long steel bars from the trucks into store. One yard contains in horizontal stacks the bars intended for making crankshafts, while the other yard receives the steel for making front axles and the rear axle shafts. Between them is a shear shed.

From the steel store the long bars are put on a gravity roller conveyor, which leads them to a shearing machine in the adjoining shed (an average distance of 80 ft.), where the bars are cut into shorter correct lengths. These pieces are then loaded into stillages, or large steel boxes, mounted on legs, styled "skids", thus allowing them to be picked up by a petrol-driven

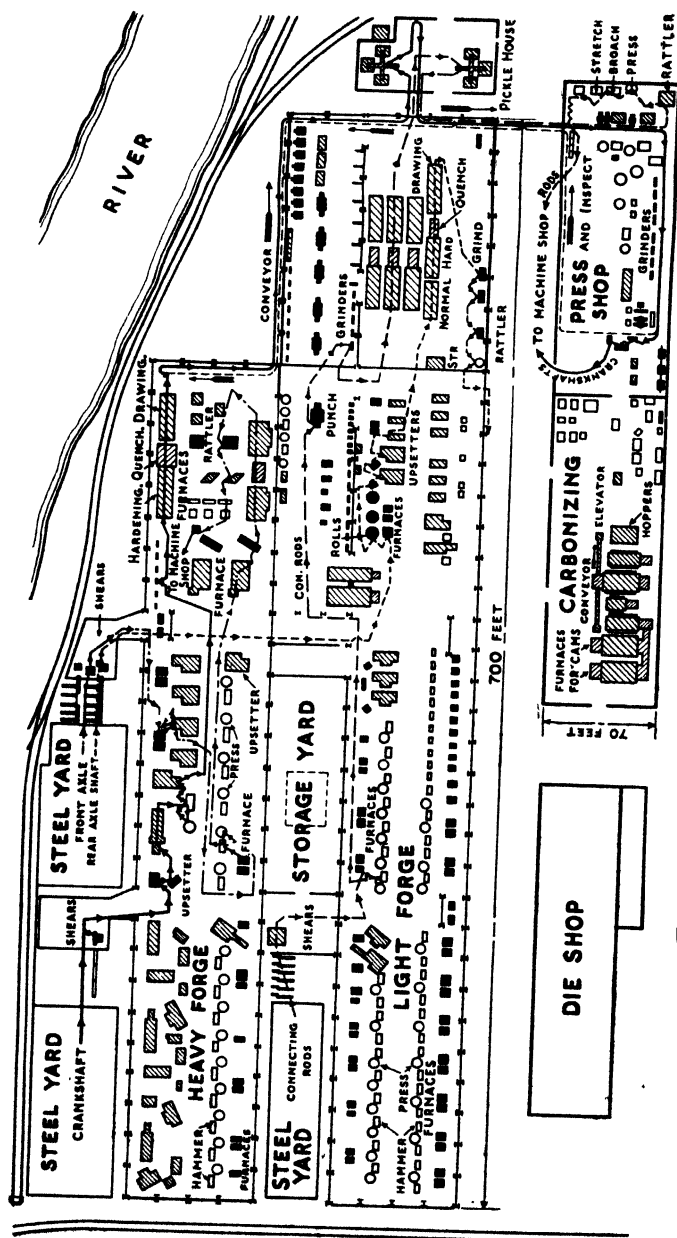


FIG. 35. PLAN OF FORGE AND HEAT TREATMENT SHOPS

lifting truck, the table of which runs underneath the skid-box. Order slips are used, stating to which hammers the cut steel bars have to be delivered.

The bars stay in the skids until wanted at the heating furnaces, when they are got hot, forged under the hammers, trimmed in the presses and (whilst still hot) loaded into skids for transport to the next process, which is usually heat treating. The "flashings" or trimmings from the dies are at once put into skid-boxes of a special tipping type, which are carried to the scrap bins by lifting trucks and there dumped.

Petrol lift-trucks are utilized throughout for moving steel from the shears to the heat-treating process, and then through the other steps that are carried on in the forge shop, including straightening and inspection. They turn in a small radius and are easily and cheaply operated. These trucks have to give 24-hour service, as the operations in the forge are often continuous during three daily shifts. The maximum journey of a loaded truck between shears, hammers and heat treating is some 500 feet.

Five petrol lifting trucks are kept in service whilst one is under repair, and 600 skid-boxes are handled by them. Each box can carry 600 lb. of short steel bars, or 2000 lb. of forgings made from them. The boxes serve as mobile stores, no material of any kind being allowed on the floor of the forge shop. All material and work is kept in the boxes, thus ensuring a tidy shop with no stagnant material lying about.

The forgings as completed are delivered by the lift-trucks to trailers standing outside of the forge shops. They are dumped into these trailers by means of a hoist, and a tractor then hauls them into the nearby machine shop.

The movement of all boxes of parts during internal transport is regulated by small slips attached to them,

which bear the order number, the name and quantity, and also the particular departments concerned. No driver of a lift-truck is allowed to move anything without one of these "move-slips." Each driver is paid on a piecework basis for the quantities handled.

Routing a Crankshaft Forging. The "routing" of a crankshaft forging may now be followed through on the plan. First, the long steel bars are taken from the open store to the shears by means of an overhead crane. From the shears the short cut bars travel in skid-boxes carried by a lift-truck to a furnace and then go to an "upsetting" machine. The same means of transport is used to take the parts to a billet furnace, on to a hammer, then to a press, and again to a hammer. The forgings then go to an "upsetter" and to a "grinder" and at length pass to the heat-treatment shop.

The time of travelling through the "hardening" furnace is controlled electrically from a central station to which are connected recording pyrometers. These register the furnace temperatures on charts. Feeding mechanism pushes the forgings through the furnace at the rate of travel set by a metallurgist.

From the above furnace the forgings are discharged one by one, and fall down into a quenching tank. An inclined double-strand tray conveyor then picks up the forgings from the tank, and delivers them to the operator feeding the "drawing," or "tempering," furnaces.

After leaving the tempering furnaces the forgings mostly go to the "pickling" department, which is housed in a separate building on the extreme right of the plan, marked "pickle house."

Small forgings are collected in steel boxes, whereas crankshafts are hung on the hooks of an overhead monorail conveyor. This chain conveyor has a long circuit of some 1500 ft., including twelve bends. Its

chain runs near the wall of the main shop, and then turns into the pickle house, where the suspended forgings are taken off the conveyor.

In the pickle house gravity roller conveyors lead the forging to and from pickling vats, where the surface scale is removed from them. The pickled forgings are put back on the long overhead conveyor, which takes them on to the next department, marked "press shop," for grinding and straightening. The empty conveyor chain then returns to the crank-shaft department, as indicated by dotted lines on the plan.

After the forgings have been straightened and inspected in the press shop, they are loaded into trailers and taken into the nearby machine shop, where numerous subsequent operations have to be performed upon them before the forgings become converted into finished motor car details.

Routing a Connecting Rod Forging. One other important forging may be traced through on the plan, namely, the connecting rod of a car engine. The narrower open steel store yard is served by a 5-ton electric overhead travelling crane of 40 ft. span, which transfers the long steel bars from railway trucks into store, and from there into the adjoining shear shed, for cutting up into short lengths.

Whilst contained in movable stillages, or steel boxes on legs, the cut bars are removed by petrol lift-trucks to the furnaces in the light forge shop, and then shaped in dies by means of presses and hammers.

These connecting rod forgings next go on to the heat-treating department (as indicated by wide dotted lines), where they are punched with a large hole, then ground, hardened, tempered, tested for hardness, and passed into the pickle house. After pickling in vats there, the forgings are put on the overhead chain and

conveyed to the press shop for cleaning, pressing, broaching, stretching and finally inspection, before being taken by trailers to the machine shop.

In a similar manner other forged details may be traced throughout the various processes, as indicated in the plan, the entire lay-out being designed to secure speedy straight-line production or the simplest routing. Every section of the plant is suitably placed in relation to the preceding and following operations, with ample space around every machine, each being individually driven by its own motor. Order and cleanliness have received close attention.

The "flashings" cut from forgings are put directly from the presses into skid-boxes, or light tipping hoppers, which are picked up and taken by lift-trucks to the scrap bins and there tipped.

Die Handling. For changing the dies on hammers and presses two electric-battery high-lift trucks are employed. These are very convenient for handling dies, and do away with the need for jib cranes. The dies are thus carried to and from hammers and presses. A similar elevating truck carries dies between the forge shop and the die-making and repairing shops. It is available also for use during furnace repairs.

This repair work is done in the basement of the forge shop, where suitable materials are stored. Furnace sections are carried by overhead travelling crane to a hatchway and lowered on to the platform of the lift-truck, which then takes them to the repair room. This truck can reach the lower level because the ground slopes at the forge shop, and the approach at one end is at basement level.

As regards the *fuel* for the furnaces, the forge shops use fuel oil, which runs from tank wagons into storage tanks in the basement. The oil is metered, then pumped through a pipe line supplying the forging furnaces.

Gas is the fuel used, however, by the heat-treating and carbonizing furnaces.

Carbonizing. A few words may be fitly added here regarding the carbonizing department shown at the bottom of the general plan, where such details as cams and worm gears are externally hardened after enrichment with carbon.

The details to be treated are packed in tubes along with a suitable carbonizing compound, and then go through the respective heating furnaces, coming out at the rear. They are then put through the adjoining reheating furnace by the aid of pneumatic pushers. On coming out of this furnace the parts are quenched in water tanks or oil tanks standing in front of the furnaces, the work being carried in large wire baskets handled by hoists.

As the cams, gears and other details come from the reheating furnace, the used material left in the boxes is dumped through a grating and taken, by a conveyor running below the floor, to the boot of a bucket elevator, where it is mixed with 50 per cent of fresh carbonizing compound and then raised to overhead hoppers, or storage bins, for reuse.

(n) GROUPING OF TOOLS AND ROUTING

Following on the above accounts of particular assembly plants and manufacturing plants in the great motor car industry, it will not be amiss here to offer a few additional remarks on the lay-out of engineering shops in general.

In the first place the *site* of the works should be chosen with an eye to securing good facilities for transport, such as its proximity to a railway or a waterway. Since the development of road transport by heavy motor lorries, however, the possession of

railway sidings has become of less vital importance than formerly. Though still desirable, it is no longer essential to success.

A good roadway connecting the works to a public highway is necessary, and may have to be specially constructed at considerable expense. It is a good plan to set the offices well back from a busy road, for the sake of both quietness and appearance. Adequate land for future extensions should also be secured. Adjacent land may grow greatly in value as the business develops.

Careful attention should be given to the question of the availability of suitable labour and of housing accommodation, not too remote for convenient access by walking or by cycling or by means of a bus service.

Other matters to be considered are the distance from supplies of heavy raw materials and from a good market for finished machinery. The former is far more important than the latter, however, since complete machines go all over the country as well as abroad. In fact the local demand for an engineering firm's products may be negligible, except in the case of small jobbing shops engaged largely on repair work.

Throughout the works generally the materials and parts in hand should take the most direct route possible; starting from the stores and finishing in the packing shop, or the shipping department whence the finished goods are dispatched.

In the machine shop the various tools must be grouped with due regard for the operations to be done on the work in progress, so as to ensure reasonable continuity. One should allow enough space for material near each machine, the parts being preferably on wheels in containers or stillages. It is important, however, to keep gangways clear of material lying about and obstructing passage ways. White guide

lines painted boldly on the floor are a distinct help to orderliness.

When arranging the internal organization of a factory making a more or less regular type of product, it is well to prepare two diagrams for one's general guidance. The first of these is a "flow" diagram or chart, which is a tabular statement or a graphical representation of all the works processes and operations set out in due sequence. The second is a "routing" diagram or plan, showing the positions of the different shops and machines in relation to one another and the actual route to be followed by the work in progress.

In the case of a narrow site the raw materials may enter the premises at one end and the finished products leave at the other end, suitable storage accommodation being arranged at each end. But where the site is roughly square the routing may be up one side and down the other side, the stores for both materials and products then being arranged at one end of the works.

The thing to be avoided as far as possible is needless zig-zagging and crossing of the parts in transit from one place to another and back again over nearly the same ground. This causes congestion and inconvenience inside the shops as well as delay and extra cost of handling.

The manner in which the various departments and machines can be connected up by means of lifting trucks and conveyors has already been shown in the plan (page 292) of a section of the works of the Willys-Overland Co.

The type of conveyor mostly favoured in this connection is the overhead monorail conveyor, on account of its great flexibility, slight amount of floor space occupied, and its economy of construction. But

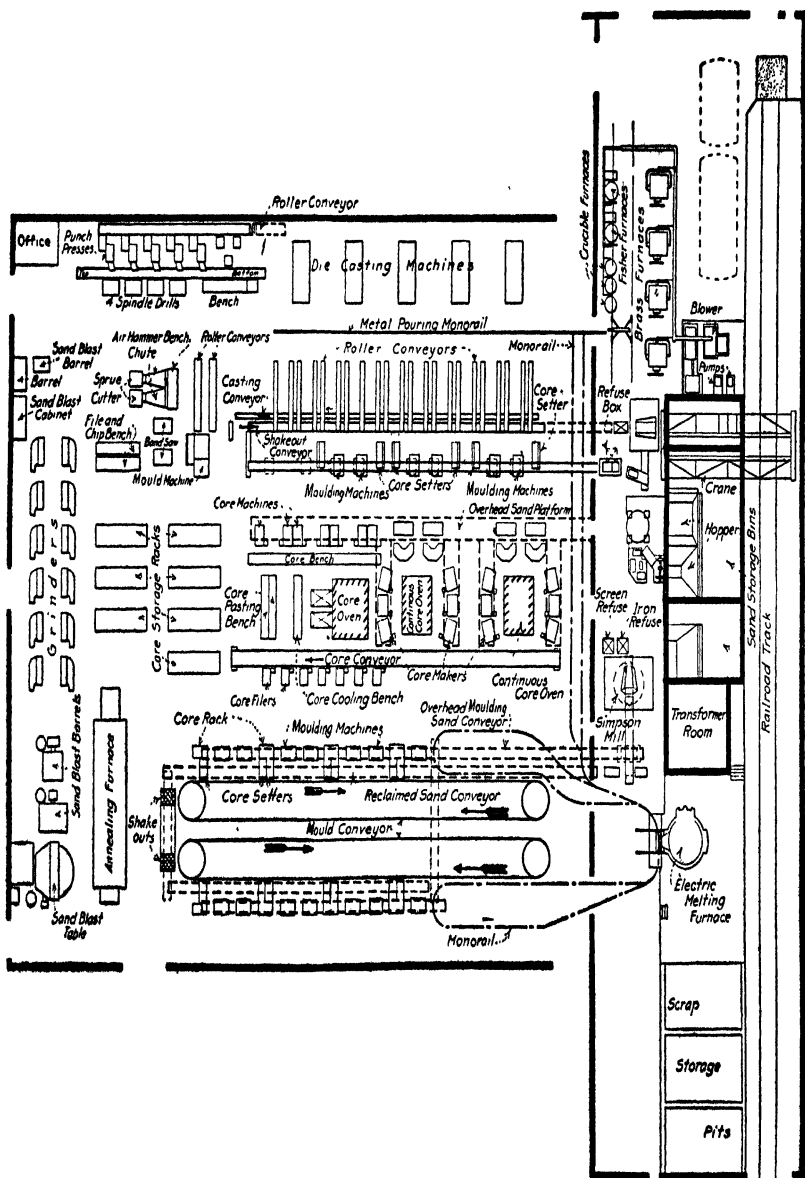
continuous chain conveyors are not always more suitable than petrol and electric trucks, which are even more flexible, though they certainly occupy much more floor space and demand good roads on which to travel, as well as the drivers needed to operate the trucks.

(o) A MECHANIZED LIGHT FOUNDRY

As a convenient example of a fully^{*} mechanized light repetition foundry one may take that of the Bendix Stromberg Carburettor Co., of South Bend, Indiana, shown in Fig. 36, which is remarkable for its compact lay-out and the fact that the iron is melted in an electric arc furnace. This foundry was specially designed with a view to the economical routing of the work going through it, no space being wasted.

It is noteworthy that this foundry is so well equipped with mechanical handling appliances that it takes only ten men to do the work for which thirty men were formerly required. From each pair of moulding machines in operation they produce 800 complete moulds in an 8-hour day; or 3200 iron castings, ranging in weight from $2\frac{1}{4}$ to 9 lb. The non-ferrous department also produces brass and aluminium castings.

The Lay-out. Raw materials are received via railway trucks, the track for which is shown on the extreme right of the plan. It extends the full length of the storage and furnace building, which is served by a 5-ton electric crane. At the receiving end of the bay there are three scrap storage pits, then a platform on which is mounted a melting furnace of the electric arc type. Beyond this furnace is the transformer room with its electrical equipment, also overhead sand storage bins and sand-preparing plant. Farther on are two groups of furnaces for the non-ferrous department of the foundry.



In the main building and just in front of the electric furnace is situated the iron pouring floor; while the non-ferrous casting floor is situated opposite the brass and aluminium furnaces. In front of the sand storage and preparation sections there is a complete core-making department for the entire foundry. Prepared sand is loaded on to a conveyor, which discharges it into overhead bins at the core-makers' stations.

This compact lay-out ensures that the hot metal and the sand have to be moved only a minimum distance, while the centrally placed core-making section can conveniently supply cores to either the iron or the brass moulders.

At the far end of the two continuous mould conveyors erected on the ferrous side of the foundry there is a vibrating screen, where the hot sand is shaken from the moulding boxes through a screen plate, and thus separated from the castings.

Sand Preparation. The sand falls on to a short sand-reclaiming conveyor placed beneath the foundry floor, from which it is transferred to a belt conveyor running parallel with the continuous mould conveyors. This belt delivers the warm sand to a reclamation room, where it is screened from bits of iron and refuse, tempered with water, and mixed in a Simpson mill. The screened sand is then raised by a bucket elevator to a revivifier for aerating, from which the now fully prepared moulding sand is delivered by a conveyor to the bins above the moulding machines.

Moulding. Along one side of each of the two endless moulding conveyors there are seven moulding machines, only four of which, however, are needed to keep the conveyor fully loaded, the other three machines being normally held in reserve, thus permitting pattern changes and overhauls to be made. The conveyor

delivers boxes, or flasks, to each moulder, who sets them on his moulding machine, then pulls a hand lever above him, and thereupon receives a charge of sand from an overhead bin. The half mould produced by the operation of the machine is then put on the conveyor.

Sand cores are delivered from several core racks to the core-setters, who work within the mould conveyor. These men set the cores in the lower or drag half of the mould, whilst it is being conveyed towards those machines making the top box or cope. The first three moulders make drag moulds and the others produce cope moulds.

After the two halves of the mould have been clamped together, they are ready for pouring whilst still on the conveyor. They at once pass along to the pouring or casting station, where the moulds are filled or "run" with molten metal from a ladle, the ladle itself being slung from an overhead runway, or monorail track, leading to the electric melting furnace.

Being only small, the castings cool down sufficiently, whilst passing slowly along the return strand of the conveyor, to permit them to be taken off the conveyor at the far end and the moulds shaken out over a grid.

The Metal. The mixture used for the iron castings made in this foundry includes pig iron, cast-iron scrap, foundry scrap, and low phosphorus steel scrap. The runners and risers (i.e. "sprue"), after having been knocked off the castings at the shake-out station, are transported to one of the covered storage pits, which extend below the floor of the storage building and are served by the 5-ton electric crane.

One storage pit or bin receives scrap from the foundry, a second contains purchased scrap iron, and a third contains pig iron and steel. The furnace charge is

made up from these bins, and is then unloaded into the furnace itself by means of the overhead travelling crane.

The melting furnace is operated so as to give a 9-ton "heat," or bath of molten metal, throughout the working day. Furnace operation is continuous, $3\frac{1}{2}$ tons of iron being tapped per hour, at a pouring spout temperature of 1400°C . Samples of iron are taken at the furnace spout every 45 minutes, from which chemical analyses and tests are made.

Pouring. A heated ladle is filled with metal at the furnace and pushed by hand a distance of about 30 ft. along an overhead runway, or branched monorail system, to one or other of the pouring zones over the endless mould conveyors, which travel very slowly. The iron is poured into several of the moulds, and whilst some other moulds are coming along, the ladle is returned to the furnace on the return overhead track, refilled and again brought to a pouring station or zone.

Meanwhile the poured moulds move slowly along the return strand of the conveyor to the shake-out, where they are pulled off on to a vibrating screen. Here the sand is shaken off the castings through a screen-plate, whence they are removed to trucks for transport to the cleaning and fettling department.

Annealing. The castings are next moved across the aisle and placed in pots ready to be annealed. These pots then go slowly down one side of the annealing furnace and, after being pushed across by a hydraulic pusher, they return to the loading end on the opposite side of the furnace. The time occupied by a complete annealing cycle is about five hours, but the castings remain in the heating zone for twelve minutes only, the temperature being 800°C . Control of the temperature is effected by a suitable pyrometric equipment.

After going through this brief annealing process (which is a very small affair compared with that adopted in malleable iron foundries), the castings are dumped into sand-blast and tumbling barrels for the removal of the dirt. Following this thorough cleaning, the castings are closely inspected for defects, tested by hydraulic pressure, and again inspected. After the grinding and machining operations, the finished iron castings are given a coat of black lacquer.

Core Ovens. The core-baking plant comprises two vertical gas-fired continuous ovens, or drying stoves, as well as an intermittent oven. Near these ovens are a number of core-making machines, while several core benches are placed in convenient proximity to avoid needless transport of the cores.

Conveyors in the Non-Ferrous Department. In this part of the foundry the metal for aluminium and brass castings is melted in a battery of oil-fired furnaces of the reverberatory type and in another row of furnaces of the crucible type. The handling equipment for sand, moulds and castings comprises a sand-preparing plant and conveyor, a series of gravity roller conveyors for the reception of the moulds, an overhead runway from the furnaces to the pouring stations, a shake-out conveyor for returning used sand, and finally a casting conveyor. In addition to this complete modern equipment, various machines for cleaning and finishing the non-ferrous castings are provided and indicated on the plan.

(p) CONVEYORS IN A BIG FOUNDRY

As a final example of the application of conveyors we will take the Ford Motor Co.'s immense foundry at Dagenham, on the Thames, where the sequence of operations is that indicated in the flow diagram Fig. 37. This is a process chart for the quantity-production of

grey iron castings from the raw materials to the finished product.

There are no fewer than seven cupolas: three of 60 in. internal diameter, three of 56 in., and one of

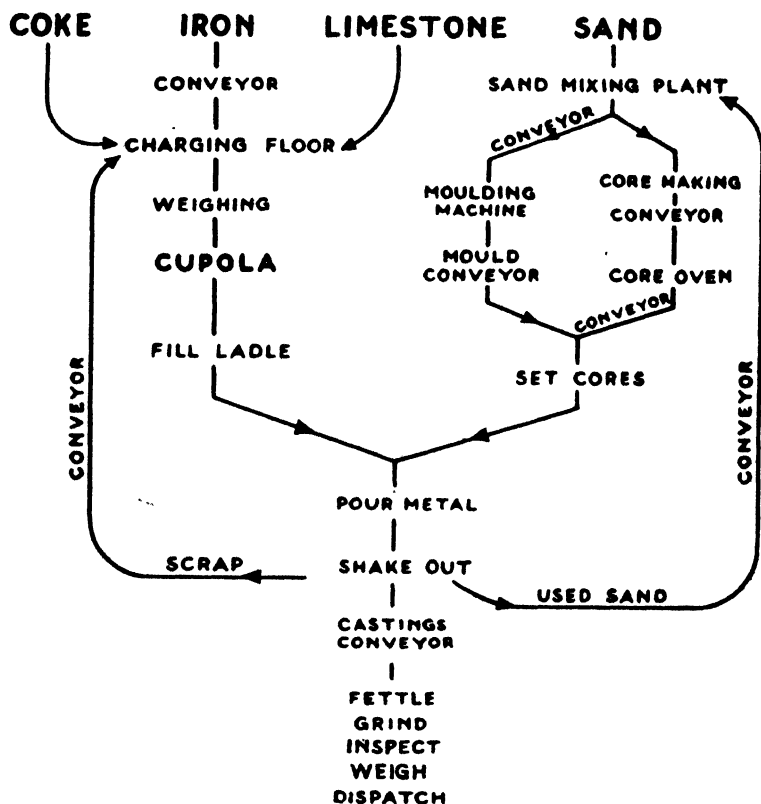


FIG. 37. FLOW DIAGRAM FOR GREY IRON CASTINGS

42 in. To the charging floor of these cupolas pig iron is raised by means of a chain conveyor, and scrap iron and limestone by the aid of a crane. Coke reaches the charging floor from overhead bunkers, fed by a 5-ton telfer and grab.

The weighing scales are of the large dial quick-reading type, while the steel wheelbarrows used on the charging floor are all of the same weight and capacity, thus facilitating the weighing of the furnace charges to give the required composition of metal, viz. 3 per cent total carbon, 3 per cent silicon, 0.2 per cent manganese, not over 0.1 per cent sulphur, and 0.04 per cent phosphorus.

The first tapping of iron from a cupola is "pigged" into a pig-casting conveyor, which returns the pigs up to the charging floor or stage.

Liquid metal on leaving a cupola spout is received in a ladle and transported by an overhead runway, fitted with a hand-traversed electric hoist, to the various pouring stations.

Meanwhile, whilst the iron is being melted in the cupolas, the dry-sand cores to form the cavities of the castings, and also the green-sand moulds to receive the metal, are being actively prepared.

Green-sand cores, as made, are placed on a conveyor of the "pendulum" or pendent type. This is really a straight monorail trolley conveyor, with long two-decker carriers hanging down freely to a few inches above the floor level. The cores are taken off the conveyor and put into a continuous core oven, heated by gas, for baking.

From the core ovens the baked cores are put on a dried-core conveyor of the steel slat type, leading to the core assembly. There they are inspected and transferred to a storage conveyor, taking the finished cores to their respective moulding conveyors. Thus a single conveyor is only a unit in a complex series of operations.

The moulding shop contains several conveyors, which run close alongside the various moulding machines. The order of operations has already been set out in

the process chart, Fig. 37. When a bottom half mould, or drag, is moulded it is at once put on a conveyor and moved slowly along towards a core-setter, who adds the cores to the mould. This moves along a little farther to a position where the top half of the mould, or cope, can be put on and clamped down, thus completing the mould just before reaching a pouring station near the end of the conveyor.

Whilst travelling along the return strand of the same conveyor the hot metal has time to set solid before reaching the shake-out station at the far end of the conveyor. The castings are there transferred to another conveyor, which takes them to the cleaning department, and the sand from the moulds goes to the sand preparation plant. The empty flasks are returned to the moulding machines via the main pendent conveyor, while the scrap or sprue goes back to the charging floor via the scrap conveyor.

Thus complete synchronization is essential to gain the fullest benefits of the conveyor system. When a mould reaches a pouring station the hot metal must be there just ready to fill the mould. If the conveyor has to wait for metal, production is at once hindered, because there is no room available for the moulders to place the moulds anywhere except on the conveyor. Thus conveyors act as pace-makers as well as transporting appliances.

Gravity Conveyors. On the borderland between movable stillages and endless chain conveyors come inclined roller runways or gravity conveyors. These simple appliances find extensive application as package conveyors in many industries (notably bottling and filling factories) and to a limited extent in engineering shops. In light repetition foundries, however, they are found suitable for taking moulding boxes short distances away from the moulding machines to

convenient pouring positions. In this way the store of moulds ready for pouring rests on a series of small freely turning rollers spaced some 6 in. apart, instead of on the foundry floor, which certainly economizes labour.

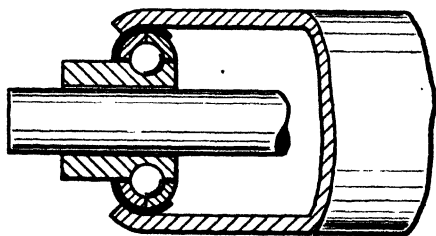


FIG. 38. DETAIL OF GRAVITY ROLLERS

(q) HANDLING APPLIANCES IN A LARGE MALLEABLE IRON FOUNDRY

Before concluding this section one may fitly refer to some useful handling appliances, other than conveyors, employed in the extensive works of Ley's Malleable Castings Co. Ltd., at Derby, where fully 500 tons per week of light malleable iron castings are produced from hematite pig iron and scrap, the individual castings ranging in weight from a few ounces up to about 200 lb. normally.

The problem of efficient mechanical handling is much complicated by the great variety of sorts and sizes of castings passing through the shops simultaneously, coupled with the long period of annealing, which interrupts the steady flow of work for about nine days. Moreover, Ley's works were not designed as a homogeneous entity on their present scale from the beginning. On the contrary they have gradually grown from a modest start throughout a period of seventy years of development.

A light steam locomotive is available for shunting

operations in the works sidings and within the yard, dealing mainly with incoming pig iron, coal and sand. One or two light petrol lorries are used for linking up the remote finishing shops at the two ends of the works, which are fully half a mile apart.

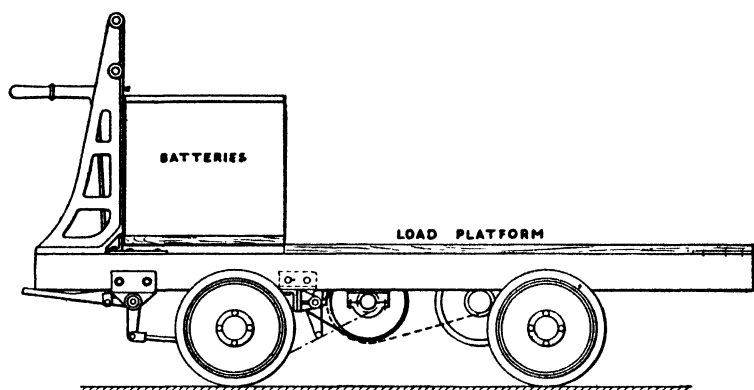


FIG. 39. OUTLINE OF A BATTERY TRUCK

From the two spacious shipping rooms, near each end of the works, finished castings are dispatched to their final destinations by railway wagons and by heavy road motor lorries. The latter come right inside the buildings, and are loaded up by hand from heaps of castings grouped in selected spaces on the floor set apart for various customers. On the other hand, steel-plate barrows are made use of for wheeling castings into the railway wagons standing on a sunk siding at one end of a shipping room.

Electric Battery Trucks. Some thirty 2-ton accumulator trucks are utilized for the service of transporting materials and castings between the different stores, foundries, annealing, and finishing shops. The type of truck used is outlined in Fig. 39, but the actual details have been gradually improved during the last twenty years. Some of these electric trucks are fitted

with platforms and others with tipping bodies, one of the latter being pictured in Fig. 40, when loaded with lumps of hard coal and standing near a hand-fired melting furnace in the foundry.

The secondary batteries are recharged every night from a low-voltage dynamo. They give good service on rough foundry work, their life being from four to five years. The solid rubber tyres last from two to three years. The wheelbase is 63 in. Though light petrol trucks have been tried, they were found less satisfactory than the electric trucks on this duty.

Some of these handy battery trucks are also employed as tractors for hauling one or two loaded bogies behind them. Secondary batteries of the lead-acid type are used, there being 20 cells giving a total E.M.F. of 40 volts.

In normal operation the driver stands on two spring-hinged pedals at the rear of the truck. The right pedal operates a brake on the motor spindle, which goes on when the foot is raised. The left pedal switches on the current to the 2 h.p. direct current motor.

Steering is done by the up and down motion of a lever-handle, preferably connected to the rear wheels below the driver. The maximum speed on the level is about 10 miles an hour, at 1400 r.p.m. of the low-voltage series-wound motor. The controller is of the drum type. When released, its handle returns automatically to the central position, thus ensuring safety.

On more general work elsewhere some battery trucks have been developed as lift-trucks for picking up and transporting stillages; also for tiering or stocking purposes, and for use as light mobile cranes.

It is interesting to note that in one particular case known to the author an overhead electric telfer, or monorail crane, running on a long steel joist track, supported by trestles over a yard, which formerly

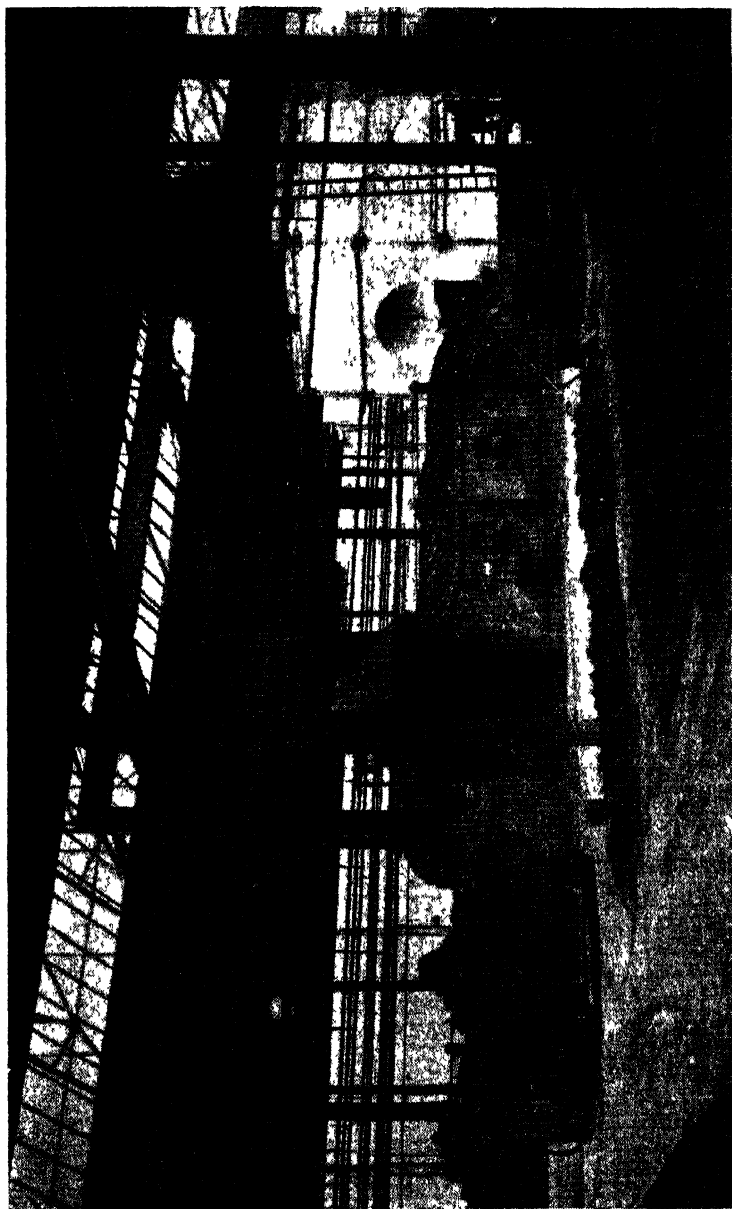


FIG. 40. VIEW OF A LOADED TRUCK AND FURNACE

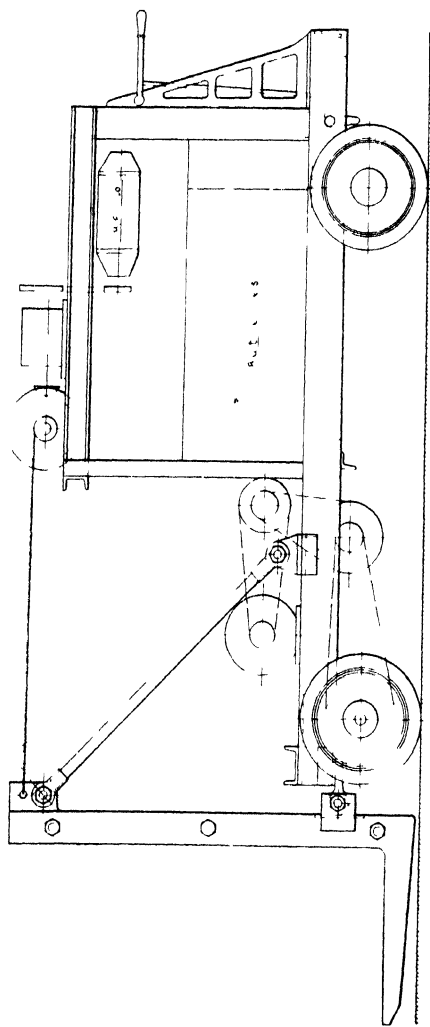
connected one large foundry to a finishing shop a considerable distance away, was recently removed after fourteen years' service as it was needing extensive repairs, while the steelwork was urgently wanted elsewhere for another purpose. As a result the castings are now taken from the foundry in question to the cleaning barrels by means of the more flexible and mobile electric accumulator trucks, running on good concrete roads.

Charging Annealing Ovens. The special mobile electric charging truck shown in Fig. 41 is employed for picking up full annealing pots and charging them into annealing furnaces. Then a week or more later the same machine brings the pots out again for dumping the contents on the iron floor of the annealing shop, after having been subjected to a long heat-treatment at a temperature of about 900°C .

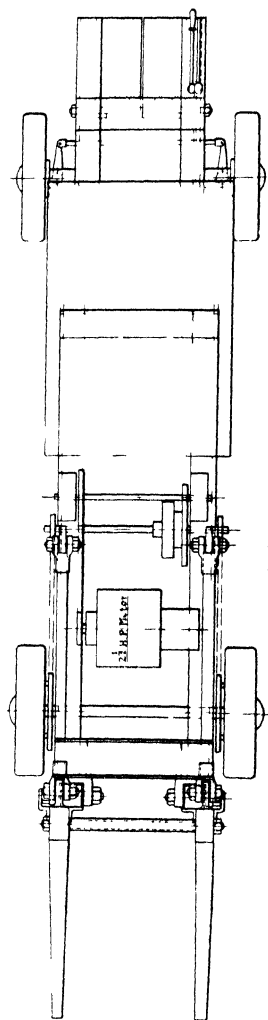
When in action, the two projecting prongs are run under a tall pot built up of five superposed sections, or open pans, resting on a heavy cast-iron fluted base and capped with sand. The lifting motor then proceeds to wind up a pair of steel ropes on small drums, thus raising the whole pot just clear of the floor, on which it is then skilfully manœuvred into the exact position required inside the oven-furnace. A full oven holds twenty-four pots, each containing a ton of castings, as well as the "scale" or packing material in which the hard castings are embedded.

The entire range of annealing ovens is fired by pulverized coal through a series of burners, fed by a pipe line from a central pulverizing and storage plant equipped with fans—a good example of the pneumatic handling of fuel.

Years ago the arduous work of charging ovens was done by hand labour, but several types of charging machines are now available to do the work much more



TO ANNEALING POT



ELECTRIC CHARGING TRUCK
FIG. 41. CHARGING TRUCK FOR ANNEALING POTS

pleasantly and quickly. An overhead travelling crane can be employed on this duty when the ovens are equipped with movable bottoms, which roll out right under the crane for loading and unloading along with the annealing pots containing the castings.

Steel Barrows. An enormous number of steel-plate hand barrows of various shapes are utilized for short-distance internal transport and for the temporary storage of castings in Ley's finishing shops, as well as for the handling of sand in the foundries. One of these handy barrows is seen in the photograph, Fig. 42, depicting a load of light castings, slung from an electric block and joist, on the point of being emptied into a Wizard centrifugal shot cleaner, for removing the scale adhering to the castings after the annealing process. In the foreground are seen numerous other castings.

Each steel barrow weighs approximately 300 lb., the actual net weight being painted on in bold figures. It forms a convenient mobile receptacle or container, in which the castings for a particular customer are collected prior to weighing them, in 8 to 12 cwt. lots, on a small platform weighing machine, having a big dial graduated into divisions representing 2 lb. Dozens of such barrows stand in rows in the shipping room, and there are hundreds more in the grinding shops, sorting shops, and distributed elsewhere throughout the works.

Thousands of tiny castings, each weighing a fraction of a pound (such as chain links) are collected in small steel tubs, or containers fitted with handles, as well as in shallow malleable iron trays, and then transported in quantities stacked on hand and electric trucks.

A Big Charging Skip. For charging a 20-ton melting furnace with pig iron and scrap a huge shovel-like skip or tray is used, slung from the hook of an electric crane by four chains. It measures 7 ft. by 5 ft. 4 in. by 18 in. deep, one end being left open. This is built



FIG. 42. STEEL BARROW FEEDING A "WIZARD" CLEANER

up of $\frac{1}{4}$ in. steel plates strengthened by stiff angles welded together, and is fitted with a renewable lining plate. Its full capacity is 4 tons. This big tray is loaded on the foundry floor from a smaller tray holding $1\frac{1}{2}$ tons of scrap, a load that can be carried on a standard electric battery truck.

Before it is possible to charge a furnace, however, a number of the cast-iron arched bungs lined with firebricks, forming its roof, must be first of all removed by the crane, thus leaving a large gap through which the scrap can be discharged from the skip, when picked up by the crane.

In contrast with this modern method, the old hand-fired 6-ton melting furnaces are still fed with scrap metal from numerous small trays, man-handled.

MOBILE CRANE AND MECHANICAL SHOVEL

Reference has already been made to the utility of mobile cranes and mechanical shovels in the yards of engineering works, and a description of these useful machines (as made by the Chaseside Engineering Co. Ltd., Enfield) will now be appended. The shovel is particularly suitable for loading up into lorries such waste products as ashes, spent foundry sand and slag, some hundreds of tons of which have to be got rid of weekly. These materials are very destructive to chain elevators.

The handy 1-ton crane depicted in Fig. 43 has a lift of $11\frac{1}{2}$ ft., the hook-block being of the swivelling type and fitted with a ball thrust bearing. Both the jib and the frame supporting it are fabricated from steel channel and angle sections by the process of electric welding. With the jib dismantled the crane weighs 3 tons, while the weight of the fixed-radius jib itself is $\frac{1}{4}$ ton.



FIG. 43. "CHASESIDE" MOBILE CRANE

This crane jib is interchangeable with the jib and the boom of the "Hi-Lift" *shovel* depicted in Fig. 44 and outlined in the drawing of a half-yard shovel, Fig. 45. At a very low cost this shovel loads loose



FIG. 44. VIEW OF "HI-LIFT" MECHANICAL SHOVEL

material from a heap on the ground up to a height of 9 ft., usually into a motor lorry, at the rate of some 40 tons per hour. It is easily operated by one man, is extremely mobile, and is also economical in fuel. Different "scoops" or "buckets" are available to suit the various materials handled, which include coal, coke, loose stones, gravel, sand, and foundry refuse.

The power unit is the same for both crane and shovel, viz. a 4-cylinder petrol engine, developing 35 b.h.p. at 1400 r.p.m., fitted with a high tension magneto, a carburettor, and a 17-gallon petrol tank. The transmission has three speeds forward and one

reverse, the shafts running in roller bearings. The multiple-disc transmission brake is operated by a clutch pedal, while the rear wheel brakes are of the internal expanding type, hand operated.

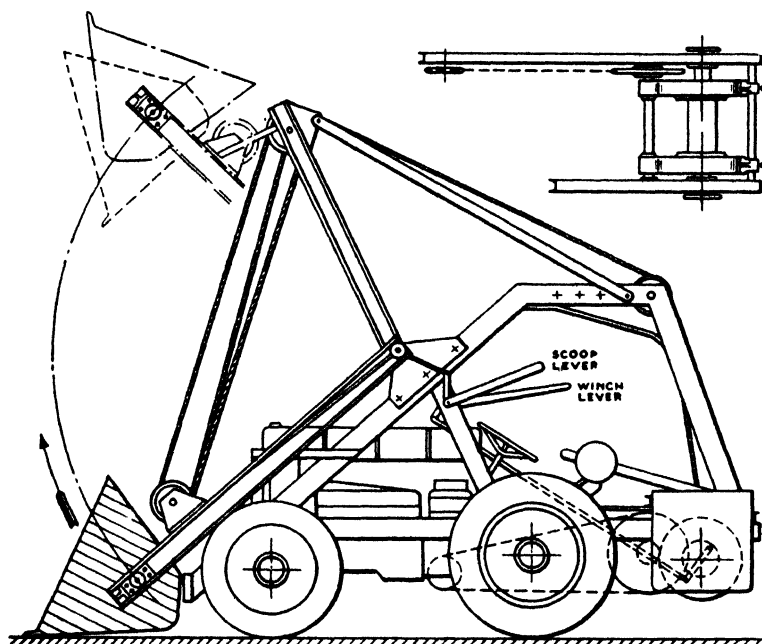


FIG. 45. DRAWING OF A HALF-YARD SHOVEL

The front axle is of the centre-pivoted type, giving a wide track, and the wheelbase is 63 in. The steering is by means of a hand wheel, steel worm and sector. The front disc wheels are equipped with heavy-duty pneumatic tyres, of 30 in. diameter by 5 in. The rear wheels are specially weighted to 8 cwt. each, so as to prevent them from lifting, when the shovel is picking up its load from the ground.

The steel rope winding gear includes a friction winch with a double friction drum, driven from the engine

by a Renold duplex chain of $\frac{3}{4}$ in. pitch. The drum shaft carries an automatic brake, having shoes lined with a suitable friction fabric. The friction roller shaft runs in ball bearings, and the drum shaft in bronze bearings. All the operations of the winch are controlled by a single hand lever.

The rope sheaves have machined grooves and are fitted with phosphor bronze bushes turning on steel pins, which are drilled for grease-gun lubrication. In order to protect the driver of the shovel from bad weather, screens of water-proof canvas with celluloid windows are provided.

In operation the shovel is run smartly into a heap of loose material with the scoop at ground level; then the scoop is raised by the winding gear high enough to clear the side of the lorry, and the machine manœuvred into a position roughly at right angles to the lorry. On pulling a lever the scoop swivels about the top centre of the boom and discharges its contents into the lorry, a good deal of dust being made in tipping when the material is fine and dry. The shovel is then promptly run round to the heap again, the scoop meanwhile being lowered, and at once refilled as before. When smartly handled, this machine will load a lorry in a few minutes.

In practice the wear on the long steel lifting rope has been found to be rather heavy. An alternative and somewhat improved design of loading shovel is now available. This employs a much shorter rope, connected to a long balanced lever or rocking beam at the end remote from the bucket. In this type of machine the bucket discharges from the bottom, instead of overturning, and there is less dust.

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